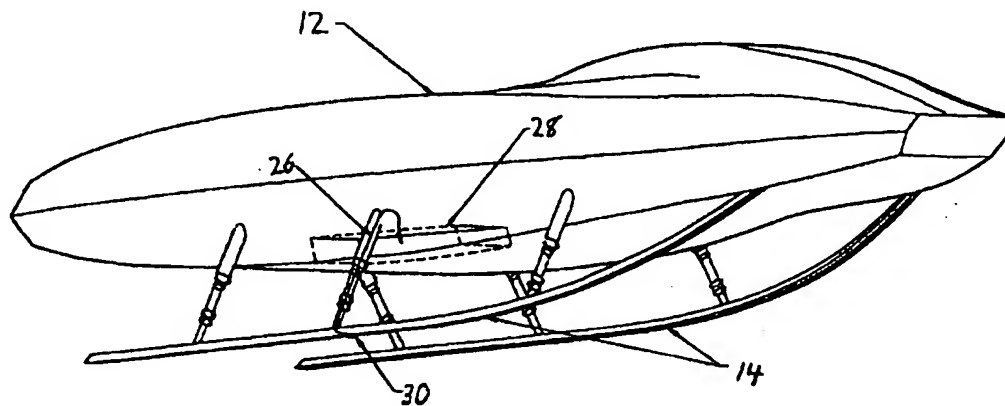




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B63B 1/20		A1	(11) International Publication Number: WO 98/08732
			(43) International Publication Date: 5 March 1998 (05.03.98)
(21) International Application Number: PCT/US97/14987		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).	
(22) International Filing Date: 26 August 1997 (26.08.97)			
(30) Priority Data: 08/703,897 27 August 1996 (27.08.96) US			
(71) Applicant: NEWPORT TECHNOLOGIES, LTD. [US/US]; 1151 Hilltop Drive, Redding, CA 96003 (US).			
(72) Inventors: ROAKE, Richard, J.; 239A Eustis Avenue, Newport, RI 02840 (US). BAKER, Stephen, C.; 881 Fort Getty Road, Jamestown, RI 02835 (US).			
(74) Agent: MROSE, James, E.; Fish & Richardson, P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).		Published With international search report.	

(54) Title: HYDROSKIING MARINE VESSEL



(57) Abstract

A marine vessel includes a buoyant vessel body (12), a propulsive device, and at least one planing element (14). The planing element lifts the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel. The ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1. The length of the planing element is at least 20 times its breadth. At least one of a plurality of attachment mechanisms (26) attached between the planing element and the buoyant vessel body is controllably adjustable in length so as to adjust an angle of attack of the planing element with respect to water. A deadrise angle adjustment mechanism (42) controllably adjusts a deadrise angle of the planing element with respect to water. The buoyant vessel body includes a ballast tank (28), and ballast piping connects the ballast tank with a ballast intake valve (30).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

- 1 -

HYDROSKIING MARINE VESSELBackground of the Invention

This invention relates to marine vessels having
5 hydroskis and more particularly relates to hydroskiing
marine vessels capable of travel at very high speeds with
active control of pitch, yaw, and roll and dynamic
damping of impact loadings, wave loadings, and
vibrations.

10 Marine vessels may be fitted with hydroskis for
the purpose of lifting the buoyant vessel body out of
contact with water at sufficiently high speeds, due to
planing action of the hydroskis, thereby reducing
hydrodynamic drag. Such a marine vessel can be steered
15 by appropriate vectoring of the thrust of its propulsion
system. During hydroskiing operation the hydroskis are
displaced downwardly with respect to the buoyant vessel
body but during low-speed operation of the marine vessel
the hydroskis may be retracted upward such that the lower
20 surfaces of the hydroskis form part of the lower surface
of the hull of the marine vessel.

Summary of the Invention

One aspect of the invention features a marine
vessel that includes a buoyant vessel body, a propulsive
25 device attached to the buoyant vessel body to propel the
buoyant vessel body at high speed, and at least one
planing element attached to the buoyant vessel body. The
planing element or elements lift the buoyant vessel body
upward and out of contact with water throughout prolonged
30 high-speed travel of the marine vessel, by virtue of
lifting action due to planing. The planing element or
elements have a length and breadth that, when multiplied,
define a planing element area (A_p). Each of the planing
elements supports a weight that, when divided by mass
35 density of water, defines a volumetric equivalent of the
weight supported by the planing element (v). The ratio

- 2 -

of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds $A_p/(v^{2/3})$ is less than 1.

Applicant believes that when $A_p/(v^{2/3})$ is less
5 than 1 the coefficient of drag (C_d) due to planing of a hydroskiing marine vessel should be relatively low, given the froude number [$F_n = \text{speed}/(\text{gravitational acceleration} \times \text{hull length})^{1/2}$] at which such a vessel would be expected to operate. Because the coefficient of drag is low, such
10 a vessel should be able to operate at high speeds with high energy efficiency.

According to another aspect of the invention the length of each of the planing elements is at least 20 times the breadth of the planing element. Applicant
15 believes that the ratio of lift to drag (L/D) due to planing of a hydroskiing marine vessel is relatively high where the aspect ratio (AR) of breadth to length of the planing element is sufficiently low, assuming that the angle of attack (α) between the skis and the water is
20 also sufficiently low. The high lift to drag ratio enables the marine vessel to operate at high speeds with high energy efficiency.

According to another aspect of the invention there are a plurality of attachment mechanisms attached to the
25 planing element or elements and the buoyant vessel body. The attachment mechanisms have strength and rigidity sufficient to transmit lifting forces from the planing element or elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with
30 water. At least one of the attachment mechanisms is controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack (α) of the planing

- 3 -

element or elements with respect to the water during the high-speed travel.

The ability to adjust the angle of attack (α) of the planing element or elements with respect to the water is advantageous because lift is a function of the angle of attack. In particular, lift (L) is equal to $\frac{1}{2}\rho v^2 A_w (dC_L/d\alpha) \alpha (\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_w is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise angle of the planing element. By appropriate adjustment of the angle of attack (α) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention provides a deadrise angle adjustment mechanism attached to the planing element or elements that controllably adjusts a deadrise angle (β) of the planing element or elements with respect to the water during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water. The ability to adjust the deadrise angle (β) of the planing element or elements with respect to the water is advantageous because lift is a function of the deadrise angle, as is discussed above. Thus, by appropriate adjustment of the deadrise angle (β) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention features one or more ballast tanks within the buoyant vessel body, one or more ballast intake valves, and ballast piping connecting the ballast tank or tanks with the ballast intake valve or valves. The ballast intake valve or valves controllably receive water during high-speed travel of the marine vessel to fill the ballast tank or tanks

- 4 -

through the ballast piping. The ballast tank or tanks make it possible to compensate for spent fuel with intake of water. By compensating for lost weight due to spent fuel it is possible to prevent undue lifting of the
5 buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel.

Another aspect of the invention features a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the
10 marine vessel and water waves, and a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system. The active vectoring of thrust
15 compensates for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

The sensor system may include, for example, an accelerometer that directly measures motion of the marine
20 vessel due to waves, or a wave sensor that detects water waves before the waves interact with the marine vessel, or both of the above combined with a sensor that measures the velocity of the marine vessel (from which the time of impact of a wave on the planing element or elements can
25 be determined). The active vectoring of thrust can provide a relatively smooth, stable ride of the marine vessel through turbulent water. The signal information from a wave sensor can include wave height information, in which case the control system can actively vector
30 thrust from the propulsive device so as to operate the marine vessel in a "platforming" mode if the wave height is relatively low and in a "contouring" mode if the wave height is relatively high. The buoyant vessel body travels a more uniform height with respect to mean water
35 level in the platforming mode than in the contouring mode

- 5 -

and travels a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

According to another aspect of the invention at least one of the attachment mechanisms that transmit lifting forces from the planing element or elements to the buoyant vessel body includes a controllable dynamic force damper. The control system actively adjusts the controllable dynamic force damper in response to signal information from the sensor system to compensate for interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel. The active adjustment of the controllable dynamic force damper can provide a relatively smooth, stable ride of the marine vessel through turbulent water.

According to another aspect of the invention the planing elements have a configuration that permits the marine vessel to ground itself solely on the planing elements. Because the marine vessel can ground itself solely on the planing elements, the buoyant vessel body need not be constructed to withstand grounding contact between the buoyant vessel body itself and solid ground.

According to another aspect of the invention the attachment mechanisms are controllably adjustable to shift the planing element or elements between a high-speed position in which the planing element or elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element or elements are displaced sideways relative to the buoyant vessel body so as to serve as fenders during docking maneuvers of the marine vessel. Because the planing element or elements can serve as docking fenders, the buoyant vessel body need not be constructed to withstand contact with other objects.

- 6 -

Numerous other features, objects, and advantages of the invention will become apparent from the following detailed description when read in connection with the accompanying drawings.

5 Brief Description of the Drawings

Figs. 1-3 are perspective drawings of a hydroski marine vessel in accordance with the invention.

Fig. 4 is an elevational front view of the vessel of Figs. 1-3, illustrating operating and retracted
10 positions of the hydroskis and operating and retracted positions of the take-off flaps.

Fig. 5 is an elevational side view of the vessel of Figs. 1-3, illustrating the range of available positions of the hydroskis due to active manipulation of
15 the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 6 is a perspective drawing of the vessel of Figs. 1-3 illustrating a ballast tank, ballast intake, and ballast piping.

20 Fig. 7 is an elevational side view of the vessel of Figs. 1-3 illustrating vertical thrust vectoring of the vessel.

Fig. 8 is a plan view of the vessel of Figs. 1-3 illustrating directional thrust vectoring of the vessel.

25 Figs. 9 and 10 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 11 is an elevational side view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

30 Fig. 12 is a plan view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 13 is an elevational side view of the vessel of Figs. 9-10 with the hydroski retracted for buoyant operation of the vessel.

- 7 -

Fig. 14 is an elevational side view of the vessel of Figs. 9-10 with the hydroski and take-off flaps in their operating positions.

Fig. 15 is an elevational side view of the vessel of Figs. 9-10, illustrating variation in the position of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 16 is a set of elevational side views of one of the engines of the vessel of Figs. 9-10 illustrating vertical thrust vectoring of the vessel.

Fig. 17 is a set of plan views of the engines of the vessel of Figs. 9-10 illustrating directional thrust vectoring of the vessel.

Figs. 18 and 19 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 20 is an elevational side view of the vessel of Figs. 18 and 19.

Fig. 21 is a cross-sectional drawing of a hydroski for use with the vessels of Figs. 1-20, adjusted for a high deadrise angle of the hydroski with respect to the water.

Fig. 22 is a cross-sectional drawing of the hydroski if Fig. 21 adjusted for a lower deadrise angle of the hydroski with respect to the water.

Fig. 23 is a block diagram of a system for active thrust vectoring and active force damping for use with the vessels of Figs. 1-20.

Fig. 24 is a chart of lift to drag ratio L/D of a planing element as a function of the aspect ratio AR of the planing element and the angle of attack α of the planing element.

- 8 -

Fig. 25 is a drag map of coefficient of drag C_d of a marine vessel as a function of $A_p/(\nu^{2/3})$ and as a function of froude number F_n .

Detailed Description

5 With reference to Figs. 1-3, marine vessel 10 includes buoyant vessel body 12 and hydroskis 14, upon which buoyant vessel body 12 travels at high speeds of between 158 and 250 knots (200 knots is normal). Engines 16, which may be, for example, Pratt and Whitney 4000
10 turbofan engines in a thrust class of about 90,000 lbs of thrust per engine, provide propulsive force to buoyant vessel body 12 while hydroskis 14 lift buoyant vessel body 12 upward and such that the buoyant vessel body is out of contact with water. At 200 knots, engines 16 are
15 typically at 50-80% of available thrust. Alternatively, air propellers, ducted fans, turbines, turbofans, or other fluid momentum imparting devices may be used. Hydroskis 14 are non-buoyant and made of titanium or carbon fiber, but in alternative embodiments buoyant
20 hydroskis or hydroskis made of other materials may be used. The dynamic lift from the hydroskis is sufficient to maintain the whole vessel in operating trim with the hydroskis planing on the surface of the water and cutting through waves.

25 Buoyant vessel body 12 is 410 feet long and has a fully-loaded weight of about 10,000-15,000 tons. Hydroskis 14 have a total length of 301.12 feet and a breadth of 4.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.0158 ("aspect
30 ratio" as used herein refers to the breadth of a planing element divided by its length, regardless of whether the total length is wetted). As is illustrated in Fig. 24, taken from an article by Kerwin, Mandel, and Lewis (M.I.T.), Journal of Ship Research, 1972, the lift to
35 drag ratio L/D of the hydroskis is relatively high when

- 9 -

the aspect ratio AR is low and the angle of attack α of the hydroskis (the longitudinal trim angle of the hydroskis relative to the water) is low (all points on this graph less than an aspect ratio of 0.25 are interpolated). In general, the length of the skis should be about 72-80% of the length of the boat and the skis should have a depth of about 8-12% of the length of the boat.

The planing element area A_p of each of the hydroskis is 1433 square feet ("planing element area" as used herein refers to the total length of a planing element multiplied by its breadth, regardless of whether the total length is wetted). Because the planing element area is relatively small compared to the dimensions of the vessel, the ratio of the planing element area to the volumetric equivalent of the weight supported by each planing element (one-half the total weight of the vessel) raised to the power of two-thirds [$A_p/(\nabla^{2/3})$] is less than 1. Fig. 25 shows the coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and froude number F_n [speed/(gravitational acceleration x hull length)^{1/2}]. Reference number 300 on the drag map represents the vessel of Figs. 1-8 loaded to 15,000 tons and travelling at 165 knots. It can be seen that the coefficient of drag C_d is relatively low when $A_p/(\nabla^{2/3})$ is less than 1 and at froude numbers at which such a vessel would be expected to operate. More preferably, $A_p/(\nabla^{2/3})$ is less than 0.9, and even more preferably, less than 0.6. Below is a list of reference numbers on the drag map of Fig. 25 and the items they represent:

- 300: vessel of Figs. 1-8 at 15 kT and 165 kts;
- 302: 6,000 lb. Unlimited Hydroplane at 200 kts (temporary condition only on the order of a few seconds);
- 304: 180 lb. waterskier at 35 kts;
- 306: 60 kT Great Lakes Ore Carrier at 25 kts;

- 10 -

- 308: 9 kT Destroyer at 35 kts;
- 310: Torpedo 3 Human-Powered Sub at 6 kts;
- 312: 800 kT Supertanker at 25 kts;
- 314: IACC Yacht at 10 kts;
- 5 316: ADCAP Torpedo at 55 kts;
- 318: Mk50 Adv. Light Torpedo at 50 kts;
- 320: Clements & Blount Planning Boat.

Due to the minimization of hydrodynamic drag on the marine vessel, at most points in the high-speed operating
10 range aerodynamic drag is substantially greater than hydrodynamic drag.

Referring to Fig. 4, during low-speed operation of the marine vessel hydroskis 14 are positioned as shown in dashed lines in order to reduce draft for entry into
15 areas of water too shallow for the marine vessel to enter with the hydroskis in the operating position, in order to reduce drag while the marine vessel is travelling at buoyant or displacement speeds, and in order for the hydroskis to serve as "fenders" during docking maneuvers.
20 During high-speed operation the hydroskis are positioned as shown in solid lines. The static water line during low-speed operation is represented by horizontal line 18, and the running water line during high-speed operation is represented by horizontal line 20. Hydroskis 14 may also
25 be positioned in an intermediate position to permit grounding of the marine vessel on the hydroskis alone. The bottom of the buoyant vessel body can consequently have a relatively light construction.

In preparation for "take-off" of the marine vessel
30 the hydroskis are moved to the high-speed position, and take-off flaps 22 are deployed in the operating position shown in solid lines in Fig. 4 (the flaps are also shown in the operating position in Fig. 2). The vessel
accelerates at a pitch of about 6 degrees (with the skis
35 pitched at 1.8 degrees relative to the vessel) in order

- 11 -

to maximize the lift coefficient. At about 40 or 45 knots the buoyant vessel body is lifted entirely out of contact with the water. As the vessel accelerates between 50 and 135 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 4, and the vessel slowly pitches down from 6 degrees to 0 degrees. The take-off flaps provide additional lift necessary to push the buoyant vessel body up and out of contact with the water below 135 knots.

10 With reference to Fig. 5, hydroskis 14 are attached to buoyant vessel body 12 by pivot 24 and oleo struts 26, which may be 2,000-ton rams, 45 feet in length and 8 feet in diameter, that use hydraulic oil, air, or rheologic fluid as a damping medium for the absorption or
15 reduction of vibrations and shock loadings associated with acoustical noise, impact loadings or wave loadings or any other loadings on hydroskis 14. The dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroskis 14. This angle of
20 attack can be adjusted in order to control the lift provided by the hydroskis, which is equal to $\frac{1}{2}\rho v^2 A_w (dC_L/d\alpha) \alpha (\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_w is the wetted area of the planing element at a given point in time, C_L is
25 coefficient of lift, and β is the deadrise (or dihedral) angle of the hydroskis. Also, oleo struts 26 can be dynamically controlled in order to compensate for unwanted forces experienced by the marine vessel due to interactions of the vessel with waves. Other hydraulic,
30 electric or mechanical devices may be substituted for oleo struts 26. The oleo struts are also used to move the hydroskis between the high-speed position (solid lines in Fig. 4), the low-speed position (dashed lines in Fig. 4), and the intermediate "grounding" position.

- 12 -

Fig. 6 shows a ballast tank 28 in buoyant vessel body 12, and a ballast intake valve 30 is provided on one of hydroskis 14 to enable ballast tank 28 to be filled with water through ballast piping in oleo strut 26.

5 Ballast tank 28 is actually one of a number of such ballast tanks within the buoyant vessel body, and ballast intake valve 30 is one of a number of such ballast intake valves on both hydroskis 14. As fuel is consumed by the marine vessel, ballast intake can be controlled by
10 controlling the ballast intake valves so as to compensate for the lost weight with intake of water into the ballast tanks. This prevents undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel due to a decrease in the
15 length of the water line and a corresponding increase in drag. A 10,000 ton boat might burn about 1,500 tons of fuel during a typical voyage.

With reference to Figs. 7 and 8, steering of the marine vessel can be accomplished through thrust
20 vectoring of engines 16. The engines include rotatable divergent/convergent nozzles 32 in the exhaust plenum that can be adjusted to vector thrust upward up to about 20°, downward up to about 20°, or in a neutral position. Similarly, engines 16 also include rotatable vanes 34 in
25 the exhaust plenum that can be adjusted to vector thrust to port up to about 20°, to starboard up to about 20°, or in a neutral position. In alternative embodiments the thrust provided by an engine or propulsive device can be vectored by other variable-geometry vanes, paddles,
30 nozzles or other fluid momentum vectoring devices situated in the thrust stream and capable of being rotated about the desired axis to direct the thrust stream in a direction appropriate to the intended vectoring. In one such design a cone of interleaved
35 petals is provided that can be directed up to about 20°

- 13 -

off of center in any given direction, the cone having a nozzle whose size can be varied by appropriate adjustment of the petals. Thrust vectoring can alternatively be accomplished by physical movement or rotation of the propulsive device itself.

Referring to Figs. 21 and 22, each hydroski 14 includes surface elements 36 and 38 pivotally connected about pivot 40. Rams 42, which may be hydraulic, air, or rheologic fluid-damped struts, are connected between surface elements 36 and 38 and a central vertical strut 44. Rams 42 can be adjusted to vary the deadrise angle β of hydroski 14 between a high value of 60 degrees or higher with respect to horizontal and a low value of 0 degrees with respect to horizontal and anywhere in-between. Figs 21 and 22 show two different configurations of the hydroski corresponding to two different deadrise angles. As is discussed above the lift provided by the hydroskis is proportional to the cosine of the deadrise angle β of the hydroskis, and thus lift can be controlled by controlling the deadrise angle through rams 42. At takeoff, the deadrise angle should be at 0 degrees, and at very high speed the deadrise angle should be high. Other hydraulic, electric or mechanical devices may be substituted for rams 42. The deadrise adjustment feature is the primary mechanism of compensation for overspeed or underspeed, which can result from interactions between the vessel and waves, aerodynamic forces, or decelerations due to maneuvering of the vessel, because this feature makes it possible to very easily relax or increase lift from the hydroskis. This ensures that the waterline length on the hydroskis stays at the correct value, and thus the center of lift of the vessel does not move backward or forward.

With reference to Fig. 23, the marine vessel is fitted with forward-looking wave sensor 46, backward-

- 14 -

looking wave sensor 48, velocity sensor 49, accelerometers 50, and fuel gauge 52, all of which transmit signal information to control computer 54. Based on this signal information the control computer
5 actively controls nozzles 32 and vanes 34 of the engines, oleo struts 26 and rams 42, ballast intake valves 30, and aerodynamic controls 55 (including ailerons for roll control, elevons for pitch control, and speed brakes for speed reduction). Wave sensors 46 and 48 may include
10 RADAR or millimeter-wave RADAR or LIDAR technology for determining the height, distance, and velocity of waves. Accelerometers 50 may be laser accelerometers.

In particular, in response to undesired accelerations of the marine vessel sensed by
15 accelerometers 50 due to interactions between the vessel and waves, or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, control computer 54 actively vectors
20 thrust from the engines in an appropriate direction and amount so as to compensate for undesired movement of the vessel. The undesired acceleration may result in pitch (rotation about a transverse axis), yaw (rotation about a vertical axis), roll (rotation about a longitudinal
25 axis), or change in velocity, or any combination thereof. In addition, control computer 54 can adjust aerodynamic controls 55 in response to undesired motion of the vessel.

The control computer 54 also, in response to
30 undesired accelerations of the marine vessel sensed by accelerometers 50 (pitch, yaw, roll, change in velocity), or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity
35 sensor 49, actively adjusts oleo struts 26 and the

- 15 -

response rate of these struts so as to actively damp or reduce impact loadings and wave loadings, including wave impact loadings. Oleo struts 26 also inherently damp or reduce vibrations and loadings wholly apart from computer control. Immediately prior to a wave hit on one of the hydroskis, control computer 54 creates a differential pulse or force in one or more of oleo struts 26 in a direction opposite to the anticipated pulse created by the wave hit. Once the wave has hit the hydroski, control computer 54 softens residual forces in oleo struts 26, measured by accelerometers 50, in a similar manner. If the residual forces are directed upward, oleo struts 26 are caused to pull the hydroski upward; if the residual forces are directed downward, the oleo struts are caused to pull the hydroski downward.

Control computer 54 also adjusts oleo struts 26 to vary the angle of attack of the hydroskis and adjusts rams 42 to vary the deadrise angle of the hydroskis in order to provide a lift that is appropriate for a given speed of the marine vessel as measured by velocity meter 49. Thus, the hydroskis are capable of maintaining appropriate lift in a planing condition over a broad range of speeds. This is important because if the lift is too high the waterline length will decrease and consequently drag will increase.

During normal operation the marine vessel operates in a platforming mode of operation in which the buoyant vessel body travels at a constant height with respect to the mean water level. This is possible because thrust vectoring can overcome any pitching forces at a given speed where the wave height does not exceed the difference between flat water normal running trim and the bottom of the buoyant vessel body (i.e., where the waves will not crash into the buoyant vessel body). Thus, the

- 16 -

buoyant vessel body need not be constructed to withstand high-speed impacts from waves.

Furthermore, if the wave height detected by wave sensor 46 is such that the wave crests would be close to five feet from the bottom of the buoyant vessel body (in the case of a 410-foot vessel), or if an adverse weather report is received, then control computer 54 can shift from the standard platforming mode of operation to a contouring mode of operation, in which the buoyant vessel body travels at a constant height with respect to the actual water surface (or at least a more constant height with respect to the actual water surface than in the platforming mode), in order to prevent impact between the waves and the buoyant vessel body. Depending on the height of the waves, the control computer 54 may operate in an intermediate mode of operation in which contouring occurs only to the extent necessary to keep the crests of the waves more than five feet below the bottom of the buoyant vessel body. In other words, the skis go through the waves in this intermediate mode, but the marine vessel is actively pitched up and down by active thrust vectoring sufficiently to ensure that the bottom of the buoyant vessel body will never impact a wave. The contouring is accomplished by active thrust vectoring of engines 16. Also, during the contouring or intermediate mode of operation, control computer 54 causes the marine vessel to travel at an angle with respect to the waves. In particular, if the marine vessel is unable or might be unable to travel over a particular large wave having a height greater than a threshold value, the control computer causes the marine vessel to make a sharp pitching turn. The severity of the turn is proportional to the greater of two limiting factors: 1) the amount of time remaining before the particular large wave could impact the vessel, or 2) the size of the large wave,

- 17 -

which determines the amount of work required and hence the amount of time required, once the wave has reached the vessel, for the vessel to execute a contouring maneuver (contouring over the large wave) such that the buoyant vessel body does not impact the wave. The contouring and intermediate modes of operation are essentially emergency modes.

Control computer 54 can maintain a constant vessel weight by causing water to be introduced into the ballast tanks through ballast intake valves 30 in response to information received from fuel gauge 52 concerning fuel consumption. The maintenance of a constant vessel weight and a constant lift ensures a near constant waterline length of the marine vessel throughout the speed range of high-speed operation, which in turn minimizes drag.

During grounding of the marine vessel on the hydroskis, the control computer controls oleo struts 26 in response to information received from accelerometers 50 and forward-looking and backward-looking wave sensors 46 and 48, in order to compensate for undesired forces due to interaction between the marine vessel and waves. If a wave hit on the port side of the vessel is imminent, the oleo struts on the starboard side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the starboard side. Likewise, if a wave hit on the starboard side of the vessel is imminent, the oleo struts on the port side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the port side.

With reference to Figs. 9-12, another embodiment of a marine vessel 110 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 112 and a single hydroski 114, upon which

- 18 -

buoyant vessel body 112 travels at high speeds in the range of 300 knots. Engines 116 are in a thrust class of about 750 lbs of thrust per engine.

Buoyant vessel body 112 is 34 feet long and has a fully-loaded weight of about 6.26 tons. Hydroski 114 has a length of 24.97 feet and a breadth of 0.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroski is 0.03. The planing element area A_p of the hydroski is 18.98 square feet. Reference number 302 on the drag map of Fig. 25 represents the vessel of Figs. 9-17 loaded to 10,000 tons and travelling at 200 knots.

During low-speed operation of the marine vessel hydroski 114 is positioned as shown in Fig. 13. During high-speed operation the hydroski is positioned as shown in Fig. 14. The static water line during low-speed operation is represented by horizontal line 118, and the running water line during high-speed operation is represented by horizontal line 120.

In preparation for "take-off" of the marine vessel the hydroski is moved to the high-speed position, and take-off flaps 122, which are mounted on the wings of the vessel, are deployed in the operating position shown in solid lines in Fig. 14. As the vessel accelerates between 5 and 50 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 13. Take-off flaps 122 assist in stability during "take-off" and "landing" of the single-hydroski marine vessel.

Because the marine vessel has a single hydroski 114 it is highly maneuverable and capable of relatively sharp cornering. As thrust vectoring or aerodynamic controls or both cause the marine vessel to turn, the lift forces provided by the hydroski pushes the vessel into the turn in a banking maneuver.

With reference to Fig. 15, hydroski 114 is attached to buoyant vessel body 112 by pivot 124 and oleo

- 19 -

struts 126. Solid and dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroski 114.

With reference to Figs. 16 and 17, engines 116 include rotatable nozzles 132 that can be adjusted to vector thrust upward, downward, or in a neutral position. Similarly, engines 116 also include rotatable vanes 134 that can be adjusted to vector thrust to port, to starboard, or in a neutral position.

Referring to Figs. 18-20, another embodiment of a marine vessel 210 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 212 and a hydroskis 214, upon which buoyant vessel body 212 travels at high speeds of between 125 and 250 knots. Engines 216 are in a thrust class of about 90,000 lbs of thrust per engine.

Buoyant vessel body 212 is 300 feet long and has a fully-loaded weight of about 1,800 tons. Hydroskis 214 have a length of 220.3 feet and a breadth of 2.14 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.097. The planing element area A_p of the hydroskis is 942.88 square feet. Reference number 304 on the drag map of Fig. 25 represents the vessel of Figs. 18-20 loaded to 1,500 tons and travelling at 165 knots.

There have been described novel and improved apparatus and techniques for marine vessel hydroskiing. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concept. For example, it is possible to construct other marine vessels according to the invention having different dimensions and performance parameters, e.g., vessels with more powerful engines that

- 20 -

travel at substantially greater speeds than those described herein.

- 21 -

What is claimed is:

1. A marine vessel comprising:

a buoyant vessel body;

a propulsive device attached to the buoyant vessel
5 body to propel the buoyant vessel body at high speed; and
at least one planing element attached to the
buoyant vessel body so as to lift the buoyant vessel body
upward and out of contact with water throughout prolonged
high-speed travel of the marine vessel by virtue of
10 lifting action due to planing;

the planing element having a length and breadth
that, when multiplied, define a planing element area;

the planing element supporting a weight that, when
divided by mass density of water, defines a volumetric
15 equivalent of the weight supported by the planing
element;

the ratio of the planing element area to the
volumetric equivalent of the weight supported by the
planing element raised to the power of two-thirds being
20 less than 1.

2. The marine vessel of claim 1 wherein the ratio
of the planing element area to the volumetric equivalent
of the total weight of the marine vessel raised to the
power of two-thirds is less than 0.9.

25 3. The marine vessel of claim 2 wherein the ratio
of the planing element area to the volumetric equivalent
of the total weight of the marine vessel raised to the
power of two-thirds is less than 0.6.

30 4. The marine vessel of claim 1 wherein
there are a plurality of planing elements attached
to the buoyant vessel body so as to lift the buoyant
vessel body upward and out of contact with water during

- 22 -

high-speed travel of the marine vessel, by virtue of lifting action due to planing;

each planing element has a length and breadth that, when multiplied, defines a planing element area;

5 each planing element supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

the weight supported by each planing element is a
10 portion of total weight supported by the plurality of planing elements; and

the ratio of the planing element area of each of the planing elements to the volumetric equivalent of the weight supported by the planing element raised to the
15 power of two-thirds is less than 1 throughout prolonged high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with water.

5. The marine vessel of claim 1 wherein the
20 propulsive device is attached directly to the buoyant vessel body.

6. The marine vessel of claim 1 wherein the high speed is greater than 100 knots.

7. The marine vessel of claim 6 wherein the high
25 speed is greater than 150 knots.

8. The marine vessel of claim 1 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

9. The marine vessel of claim 1 wherein the at
30 least one planing element is buoyant.

- 23 -

10. The marine vessel of claim 1 wherein the at least one planing element is non-buoyant.

11. A marine vessel comprising:

a buoyant vessel body;

5 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;

the planing element having a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

15 12. The marine vessel of claim 11 wherein the length of the planing element is at least 40 times the breadth of the planing element.

13. The marine vessel of claim 12 wherein the length of the planing element is at least 100 times the breadth of the planing element.

14. The marine vessel of claim 11 wherein there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

25 each planing element has a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

- 24 -

15. The marine vessel of claim 11 wherein the propulsive device is attached directly to the buoyant vessel body.

16. The marine vessel of claim 11 wherein the
5 high speed is greater than 100 knots.

17. The marine vessel of claim 16 wherein the high speed is greater than 150 knots.

18. The marine vessel of claim 11 wherein the prolonged high-speed travel has a duration on the order
10 of one or more hours.

19. The marine vessel of claim 11 wherein the at least one planing element is buoyant.

20. The marine vessel of claim 11 wherein the at least one planing element is non-buoyant.

15 21. A hydroski assembly comprising:
a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and
20 a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to
25 lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel

- 25 -

body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

22. The hydroski assembly of claim 21 wherein the
5 attachment mechanism that is controllably adjustable in length comprises a strut.

23. The hydroski assembly of claim 22 wherein the strut is an oleo strut that is controllably adjustable in length.

10 24. The hydroski assembly of claim 21 wherein one of the attachment mechanisms other than the attachment mechanism that is controllably adjustable in length comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body
15 through the pivot mechanism.

25. The hydroski assembly of claim 21 wherein the hydroski is buoyant.

26. The hydroski assembly of claim 21 wherein the hydroski is non-buoyant.

20 27. A hydroski assembly comprising:
a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and
25 a deadrise angle adjustment mechanism attached to the hydroski and constructed to controllably adjust a deadrise angle of the hydroski with respect to the water during the high-speed travel of the marine vessel in

- 26 -

which the buoyant vessel body is lifted upward and out of contact with the water.

28. The hydroski assembly of claim 27 wherein:
the hydroski comprises a plurality of surface
5 elements extending the length of the hydroski, the
plurality of surface elements being pivotally attached to
each other along the length of the hydroski about at
least one pivot; and

the deadrise angle adjustment mechanism comprises
10 a plurality of struts, attached to the surface elements
of the hydroski, that are controllably adjustable in
length during the high-speed travel of the marine vessel
in which the buoyant vessel body is lifted upward and out
of contact with the water, so as to adjust an angle
15 between the surface elements about the pivot to vary a
deadrise angle of the hydroski with respect to the water
during the high-speed travel.

29. The hydroski assembly of claim 27 wherein the
hydroski is buoyant.

20 30. The hydroski assembly of claim 27 wherein the
hydroski is non-buoyant.

31. The hydroski assembly of claim 27 further
comprising a plurality of attachment mechanisms attached
to the hydroski and constructed for attachment to the
25 buoyant vessel body, the attachment mechanisms having
strength and rigidity sufficient to transmit lifting
forces from the hydroski to the buoyant vessel body to
lift the buoyant vessel body upward and out of contact
with water, at least one of the attachment mechanisms
30 being controllably adjustable in length during the high-
speed travel of the marine vessel in which the buoyant

- 27 -

vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

32. A marine vessel comprising:

- 5 a buoyant vessel body;
- a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body
- 10 upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;
- at least one ballast tank within the buoyant vessel body;
- 15 at least one ballast intake valve; and
- ballast piping connecting the ballast tank with the ballast intake valve;
- the ballast intake valve being arranged to controllably receive water during high-speed travel of
- 20 the marine vessel to fill the ballast tank through the ballast piping.

33. A marine vessel comprising:

- a buoyant vessel body;
- a propulsive device attached to the buoyant vessel
- 25 body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action
- 30 due to planing;
- a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

- 28 -

a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system to
5 compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

34. The marine vessel of claim 33 wherein the sensor system comprises at least one accelerometer that
10 directly measures motion of the marine vessel due to waves.

35. The marine vessel of claim 33 wherein the sensor system comprises a wave sensor that detects water waves, and wherein the signal information provided by the
15 sensor system comprises information from which anticipated motion of the marine vessel due to water waves can be predicted.

36. The marine vessel of claim 33 wherein the propulsive device comprises a plurality of independent
20 propulsion units controlled by the control system.

37. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises pitch motion.

38. The marine vessel of claim 33 wherein the
25 undesired motion of the marine vessel comprises yaw motion.

39. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises roll motion.

- 29 -

40. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises a change in velocity.

41. The marine vessel of claim 33 further
5 comprising a directional control system connected to the propulsive device to actively vector thrust from the propulsive device to steer the marine vessel.

42. The marine vessel of claim 33 wherein the
10 signal information pertaining to interaction between the marine vessel and the water waves comprises wave height information, and wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in a platforming mode if the wave height is relatively low and in a contouring
15 mode if the wave height is relatively high, the buoyant vessel body travelling a more uniform height with respect to mean water level in the platforming mode than in the contouring mode and travelling a more uniform height with respect to actual water surface in the contouring mode
20 than in the platforming mode.

43. The marine vessel of claim 42 wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in an intermediate mode if the wave height is
25 intermediate, the buoyant vessel body, in the intermediate mode, travelling a more uniform height with respect to mean water level than in the contouring mode but a less uniform height with respect to mean water level than in the platforming mode, and travelling a more
30 uniform height with respect to actual water surface than in the platforming mode but a less uniform height with

- 30 -

respect to actual water surface than in the contouring mode.

44. A marine vessel comprising:
- a buoyant vessel body;
 - 5 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
 - at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed
 - 10 travel of the marine vessel, by virtue of lifting action due to planing;
 - a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity
 - 15 sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;
 - at least one of the attachment mechanisms comprising a controllable dynamic force damper;
 - 20 a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;
 - a control system connected to the sensor system and to the controllable dynamic force damper and
 - 25 configured to actively adjust the controllable dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

- 30 45. The marine vessel of claim 44 wherein the controllable dynamic force damper dynamically dampens loadings and vibrations experienced by the planing

- 31 -

element apart from adjustment of the controllable dynamic force damper by the control system.

46. The marine vessel of claim 44 wherein the attachment mechanism that comprises the controllable dynamic force damper comprises a strut.

47. The marine vessel of claim 44 wherein one of the attachment mechanisms other than the attachment mechanism that comprises the controllable dynamic force damper comprises a pivot mechanism constructed for direct attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

48. The marine vessel of claim 44 wherein the high speed is greater than 100 knots.

49. The marine vessel of claim 48 wherein the high speed is greater than 150 knots.

50. The marine vessel of claim 44 wherein the planing element is buoyant.

51. The marine vessel of claim 44 wherein the planing element is non-buoyant.

52. A marine vessel comprising:
a buoyant vessel body;
a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action;
and

- 32 -

a plurality of attachment mechanisms attached to the planing elements and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing
5 elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the planing elements having a configuration that permits the marine vessel to ground itself solely on the planing elements.

10 53. The marine vessel of claim 52 wherein the attachment mechanisms are controllably adjustable to shift the planing elements between a high-speed position in which the planing elements are displaced in a downward direction relative to the buoyant vessel body during the
15 high-speed travel of the marine vessel, and a low-draft position in which the planing elements are retracted upwardly so as to reduce draft for entry of the marine vessel into shallow water.

20 54. The marine vessel of claim 53 wherein the configuration of the planing elements that permits the marine vessel to ground itself solely on the planing elements is the low-draft position.

25 55. The marine vessel of claim 53 wherein the low-draft position of the planing elements reduces hydrodynamic drag during low-speed operation of the marine vessel in which the buoyant vessel body is in contact with water.

30 56. The marine vessel of claim 52 wherein at least one of the attachment mechanisms comprises a dynamic force damper.

- 33 -

57. The marine vessel of claim 56 further comprising:

- a sensor system attached to the buoyant vessel body to provide signal information pertaining to
5 interaction between the marine vessel and water waves during grounding of the marine vessel;
- a control system connected to the sensor system and to the dynamic force damper and configured to adjust the dynamic force damper in response to the signal
10 information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the grounding of the marine vessel.

58. A marine vessel comprising:

- a buoyant vessel body;
- 15 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed
20 travel of the marine vessel, by virtue of lifting action; and
- a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity
25 sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;
- the attachment mechanisms being controllably adjustable to shift the planing element between a high-
30 speed position in which the planing element is displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element is displaced sideways relative to the buoyant vessel body so

- 34 -

as to serve as a fender during docking maneuvers of the marine vessel.

59. The marine vessel of claim 58 wherein the at least one planing element comprises a plurality of
s planing elements.

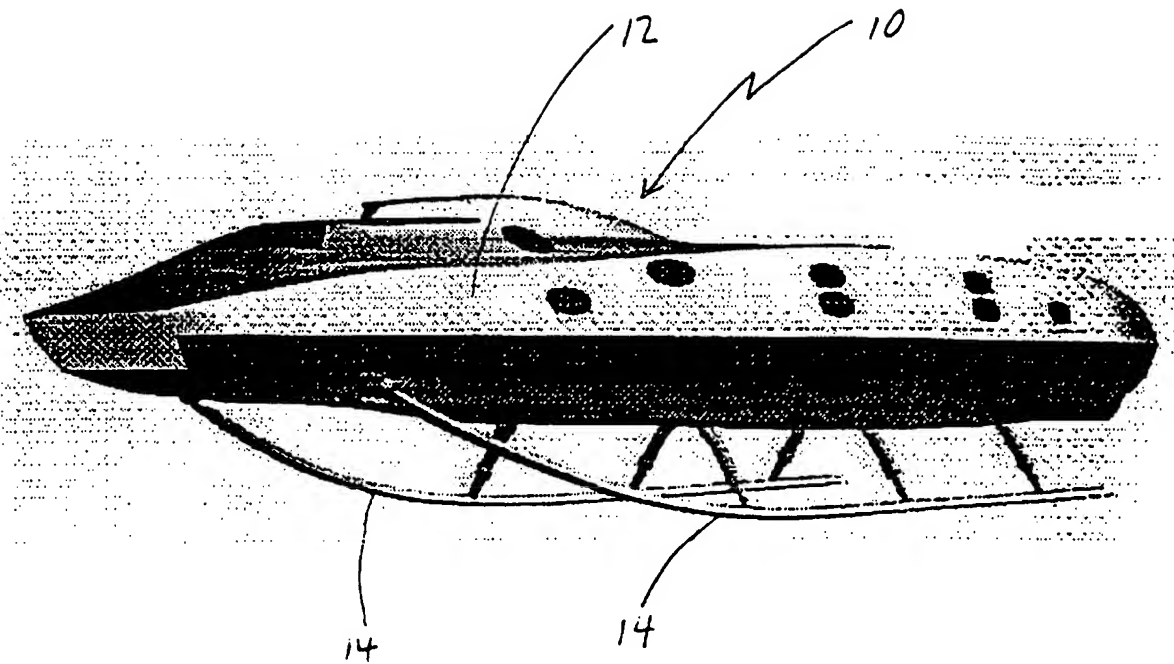


Fig.1

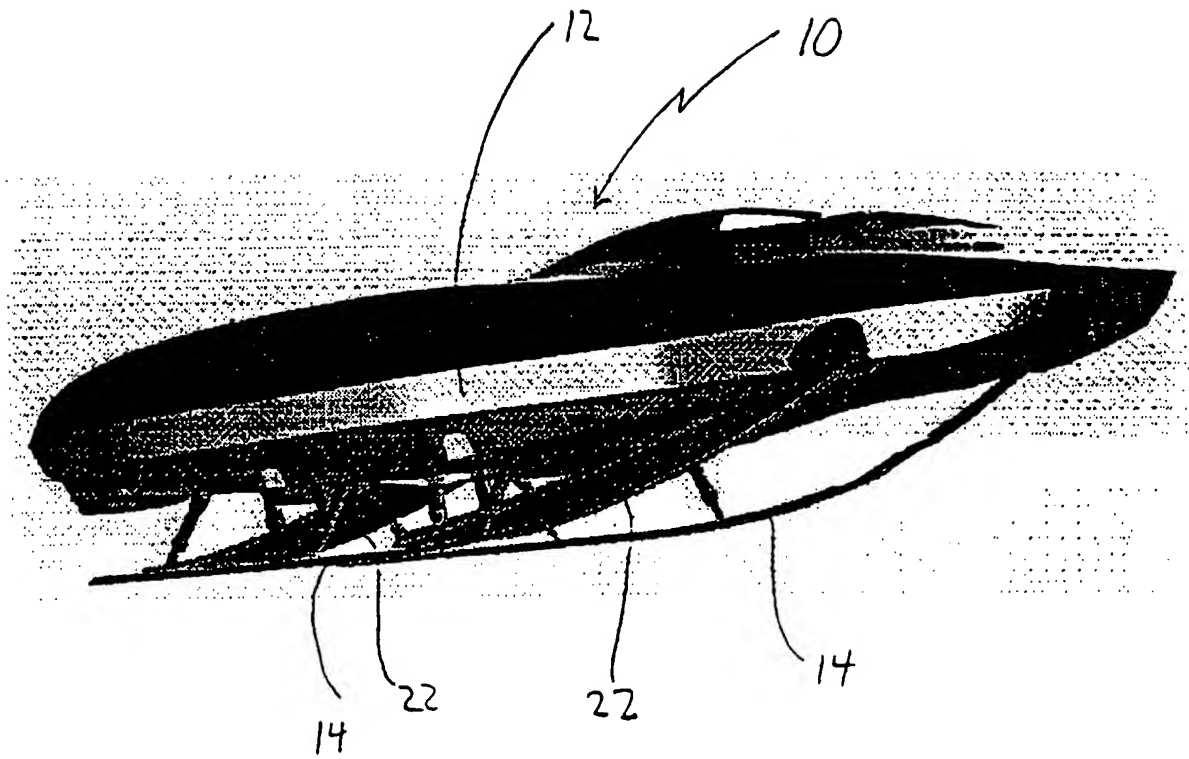


Fig.2

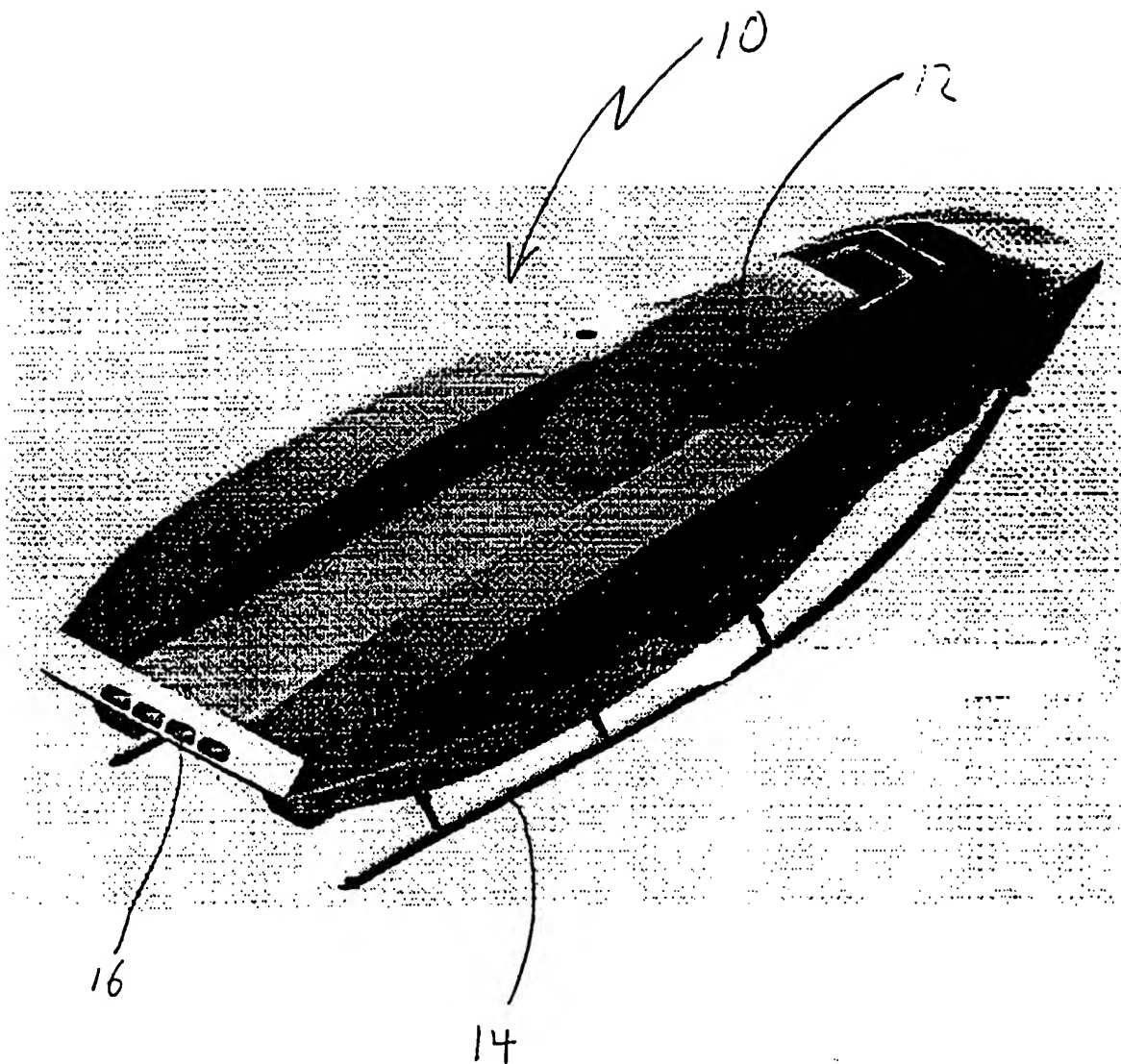
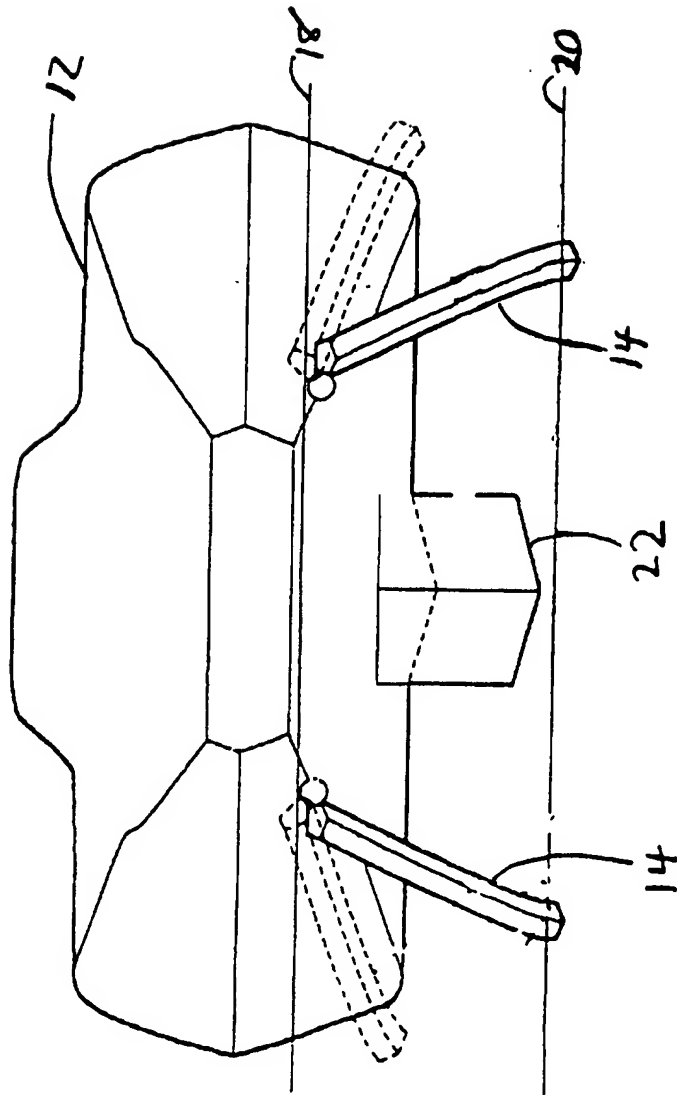


Fig.3

Fig.4



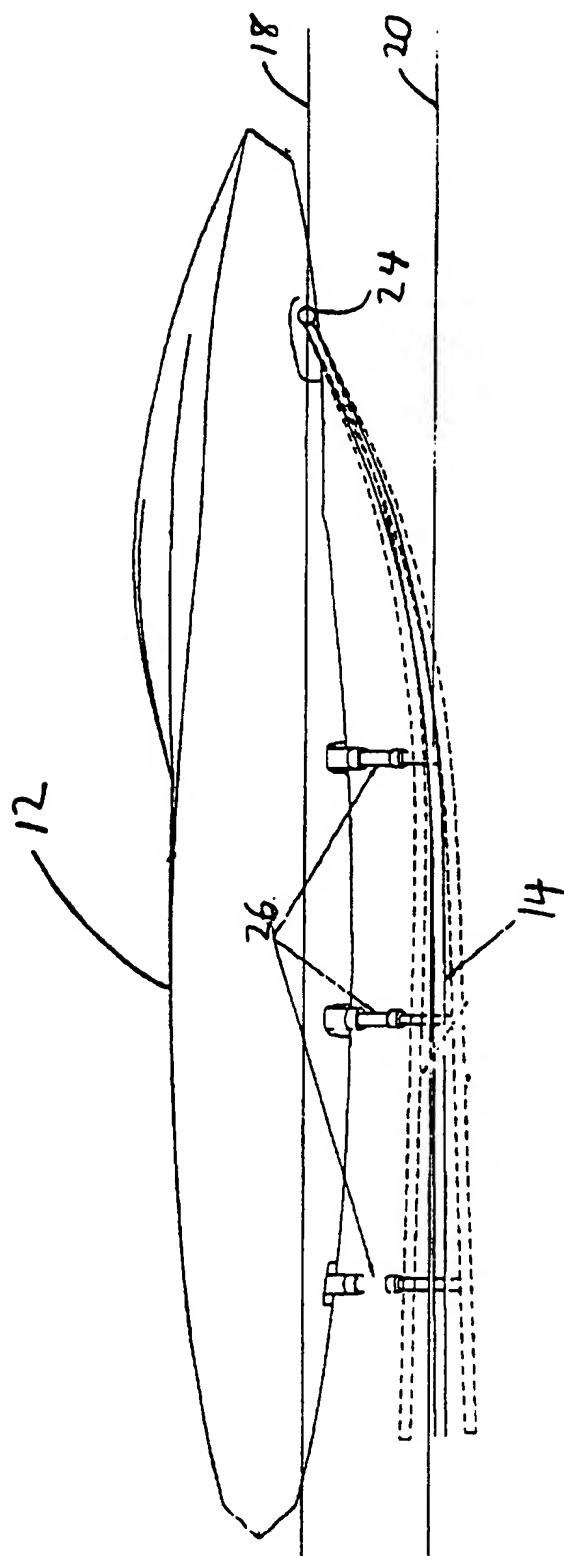


Fig.5

Fig.6

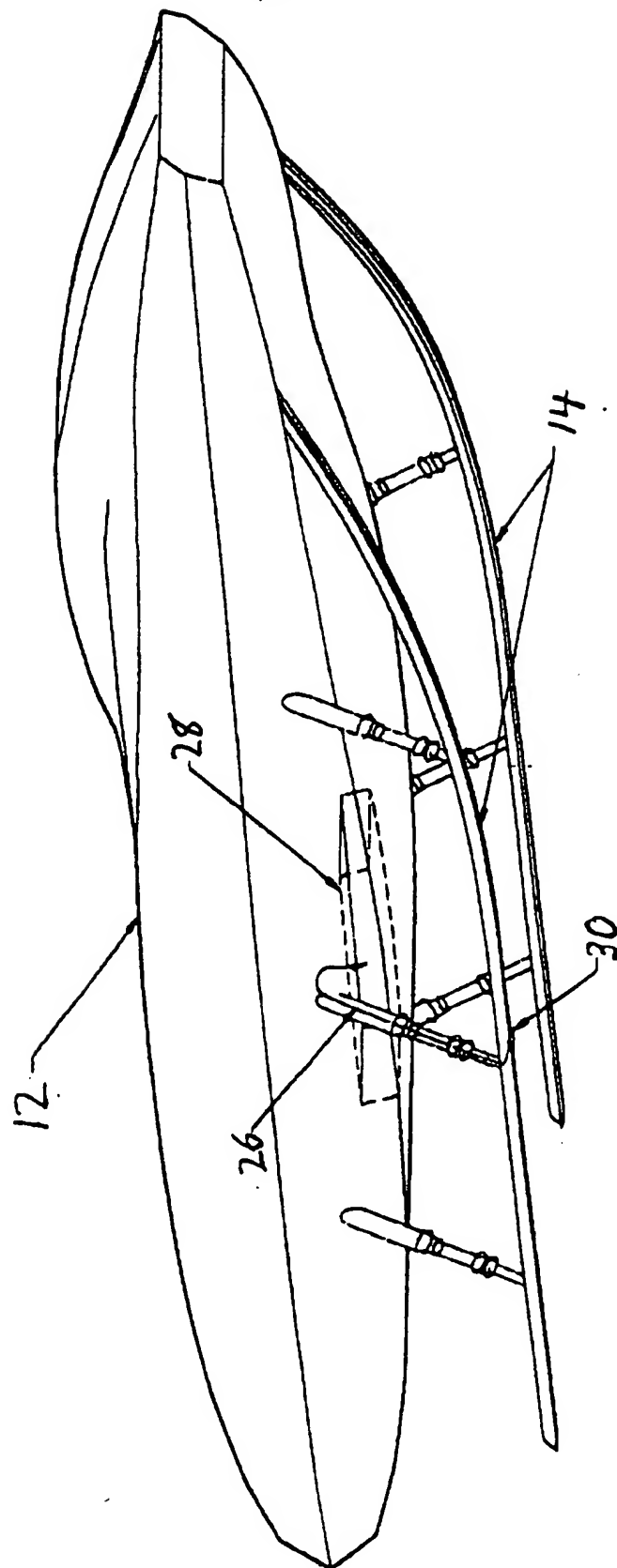


Fig.7

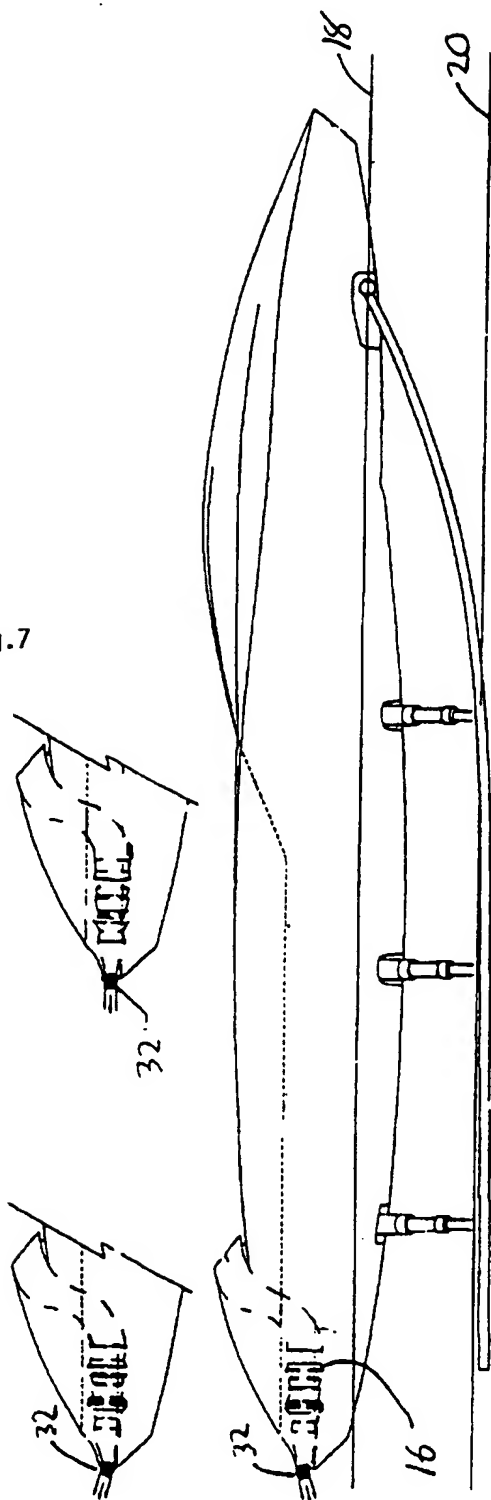
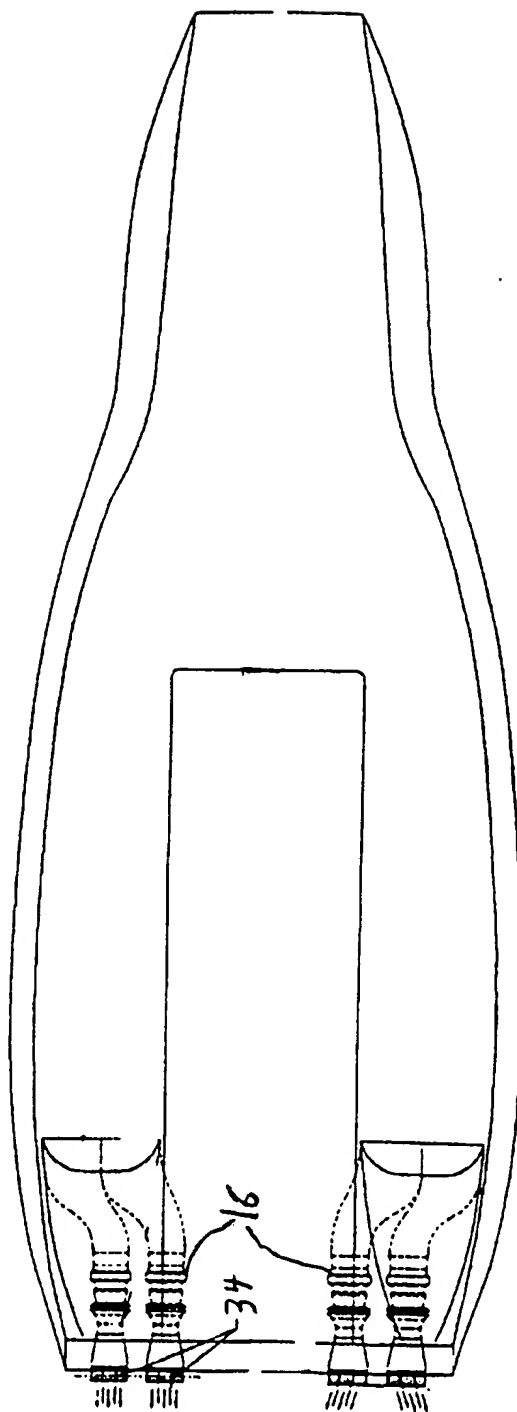


Fig.8



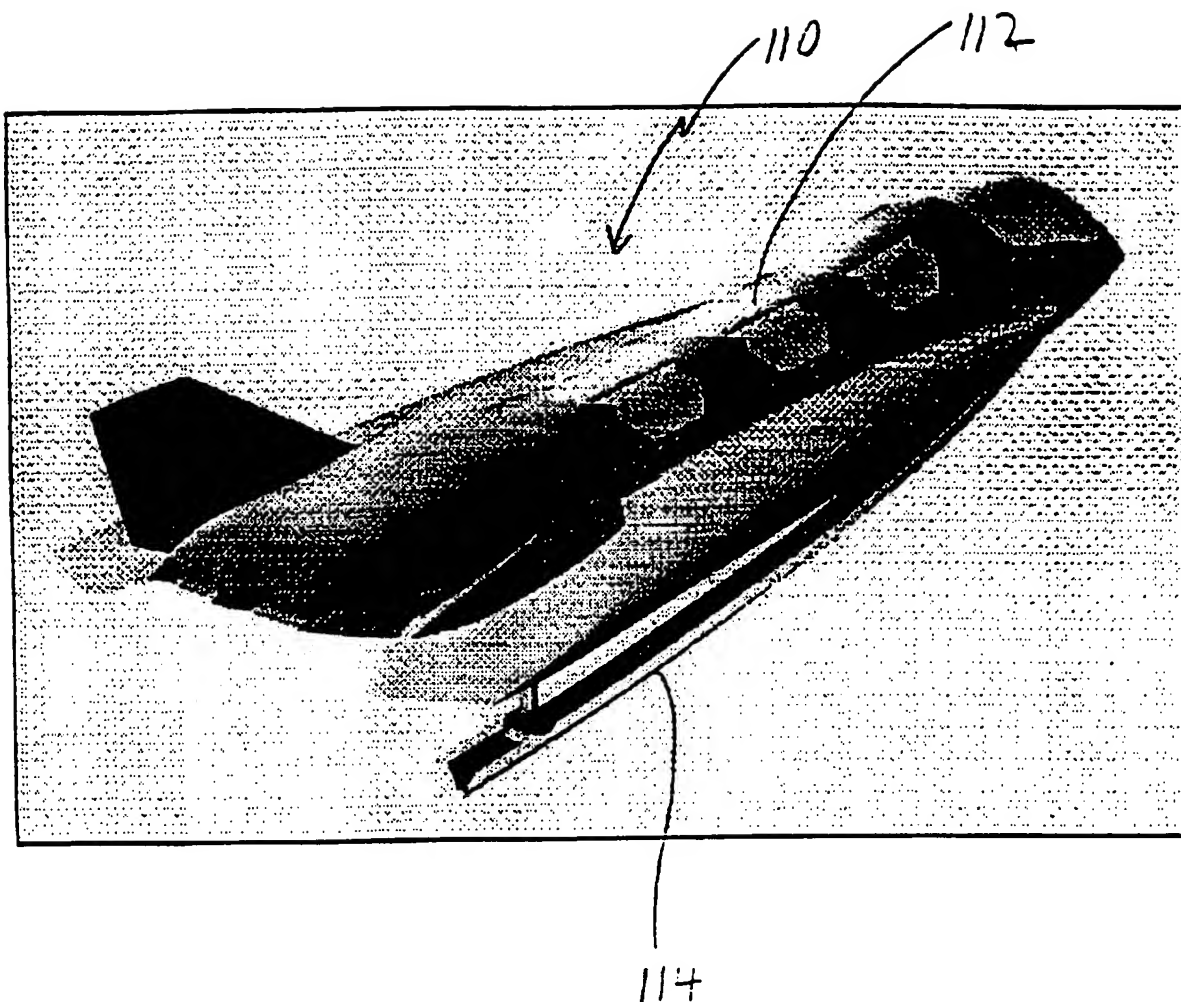


Fig. 9

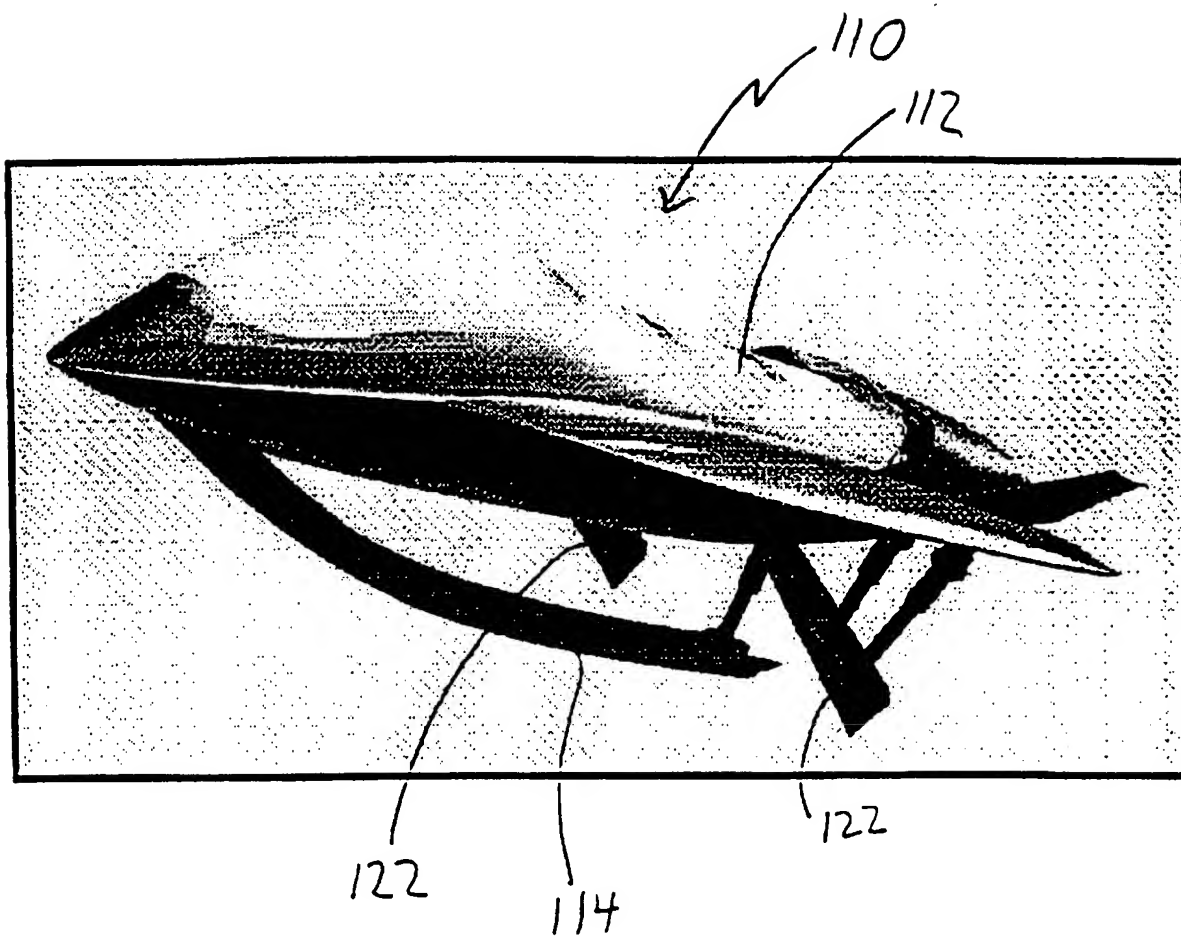


Fig.10

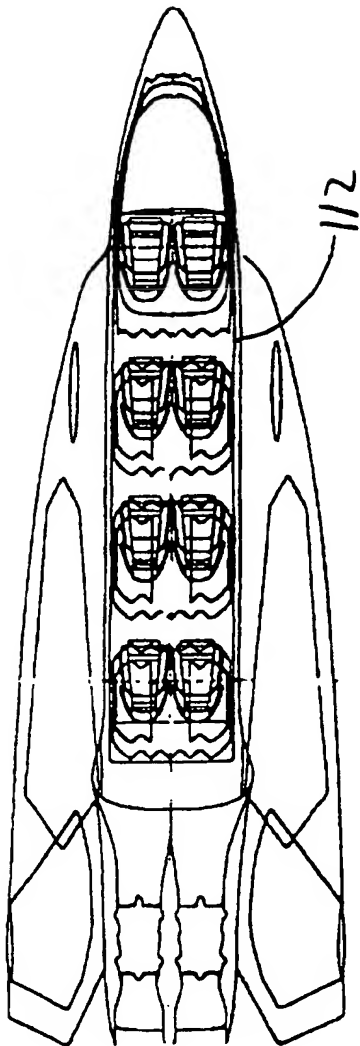


Fig. 11

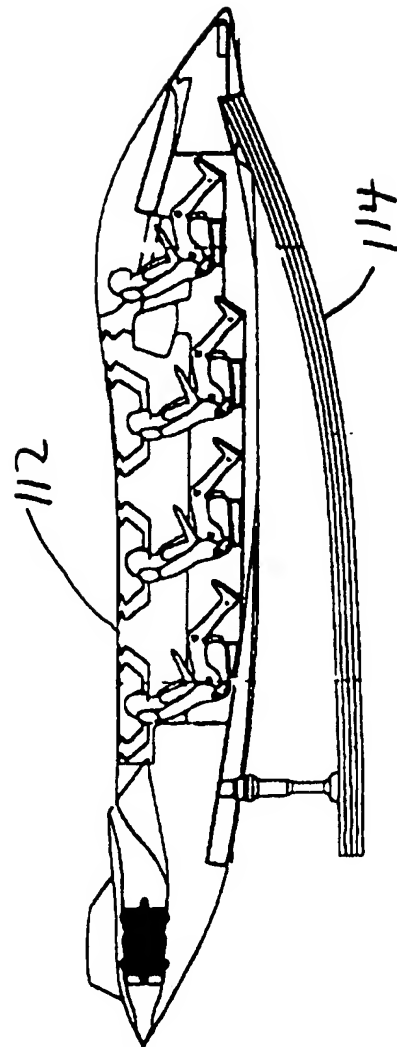
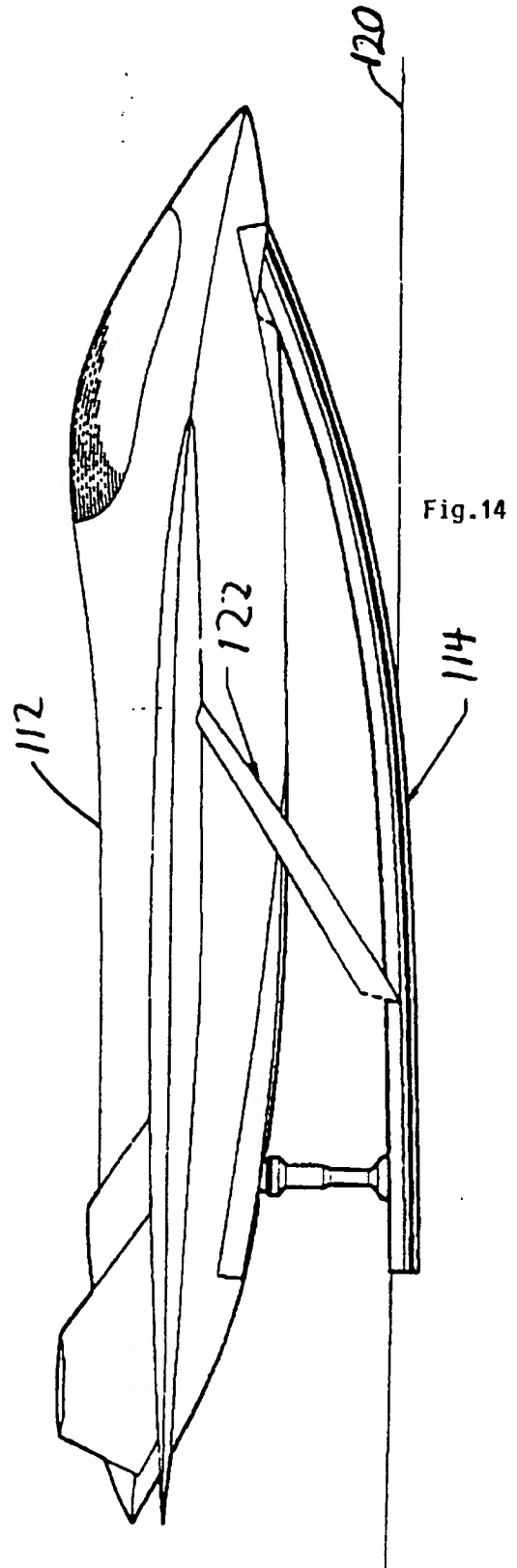
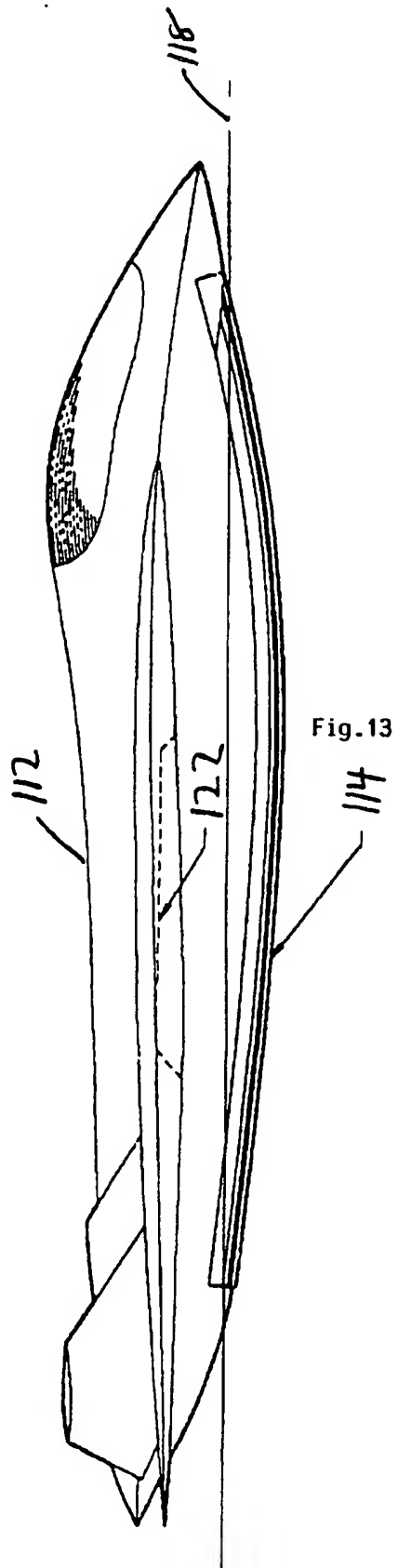


Fig. 12



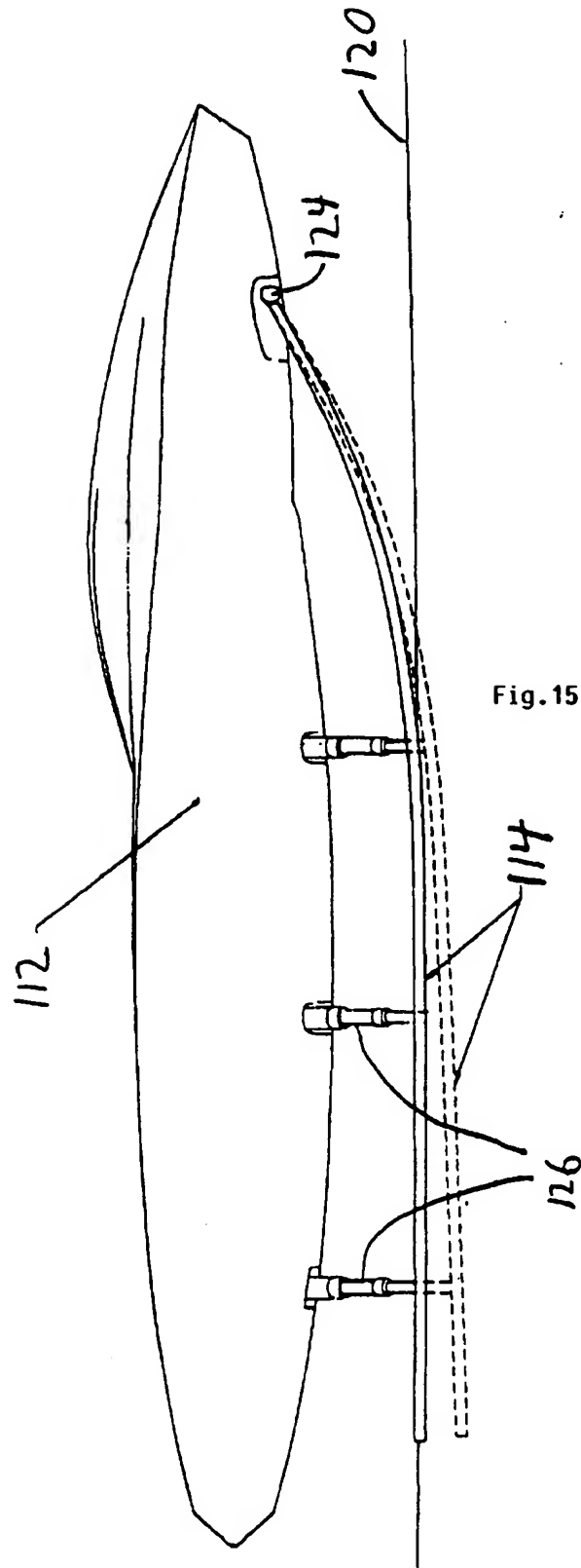


Fig.17

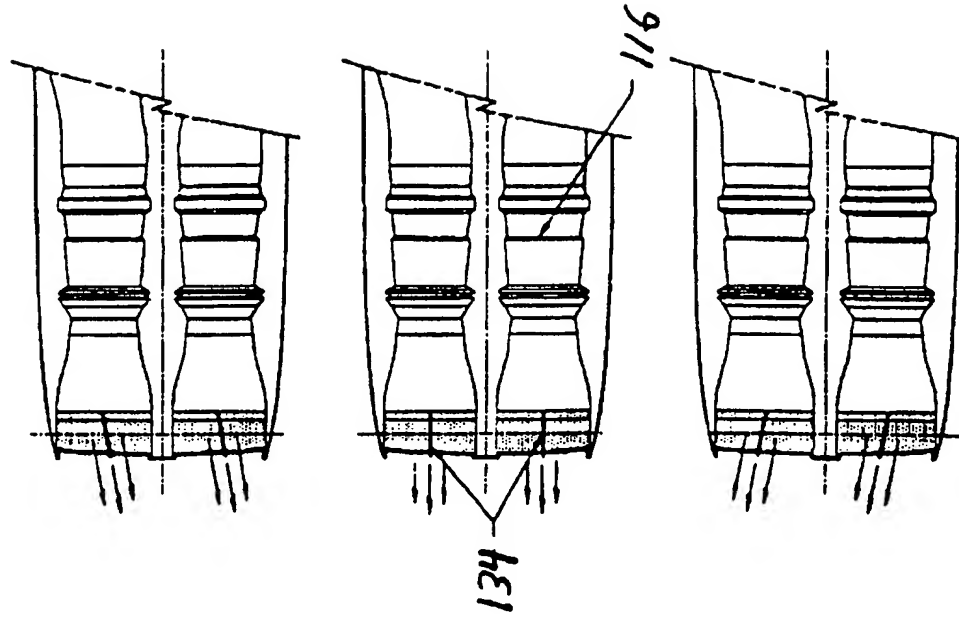
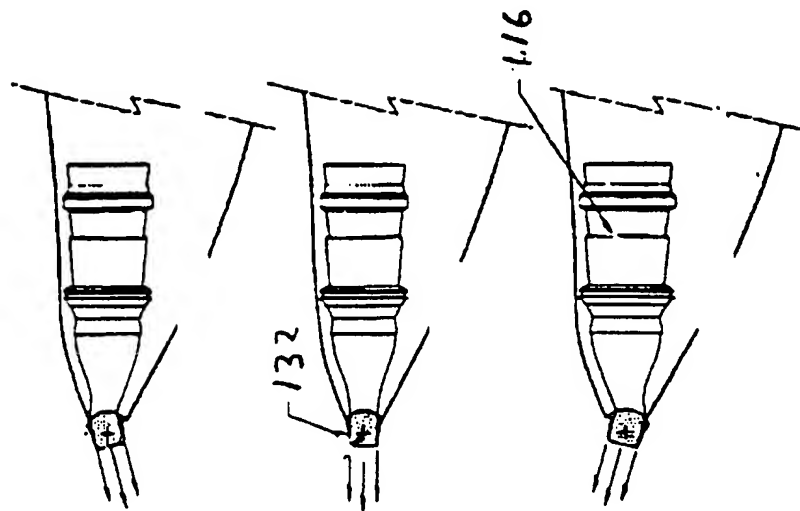


Fig.16



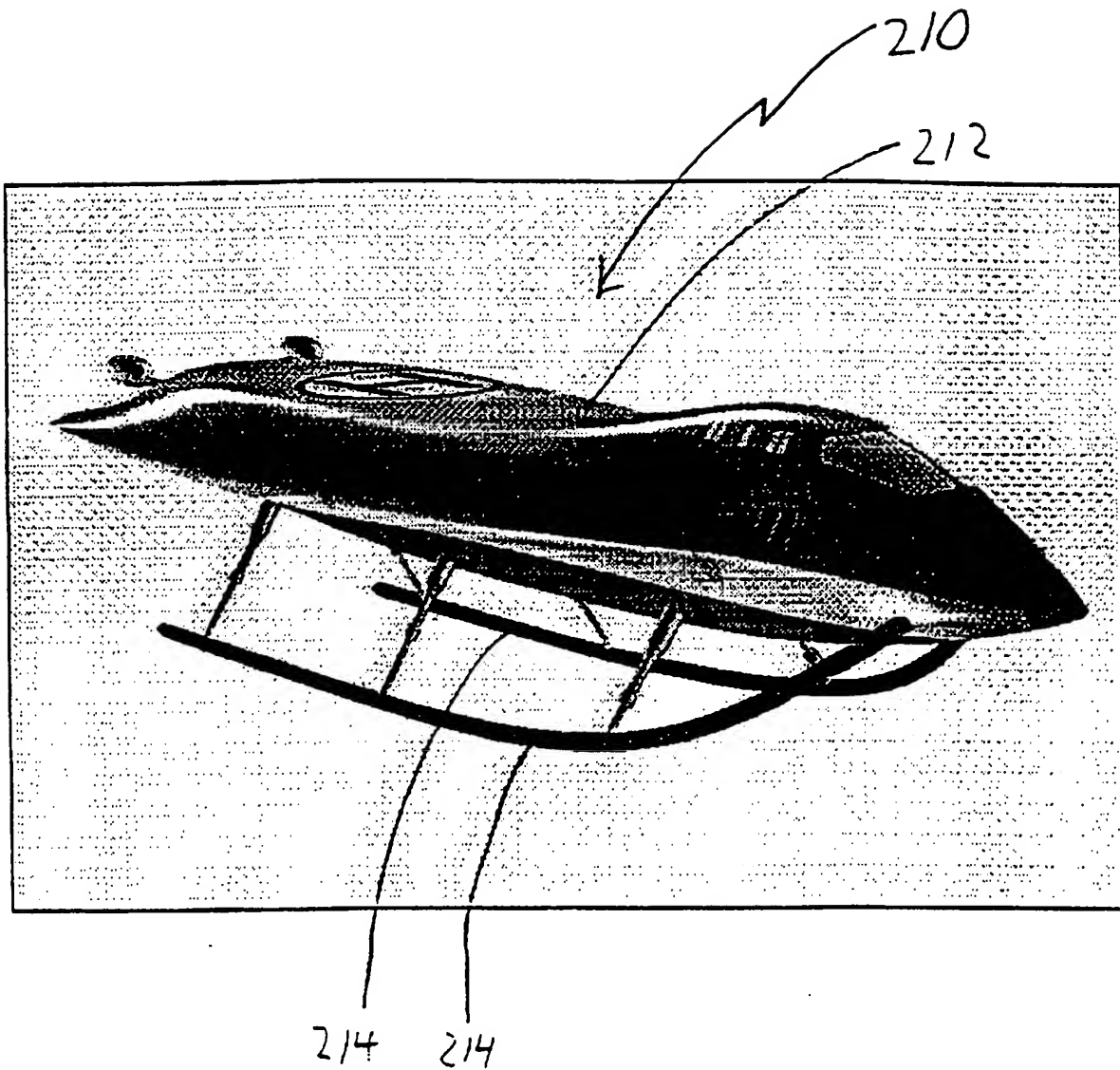


Fig.18

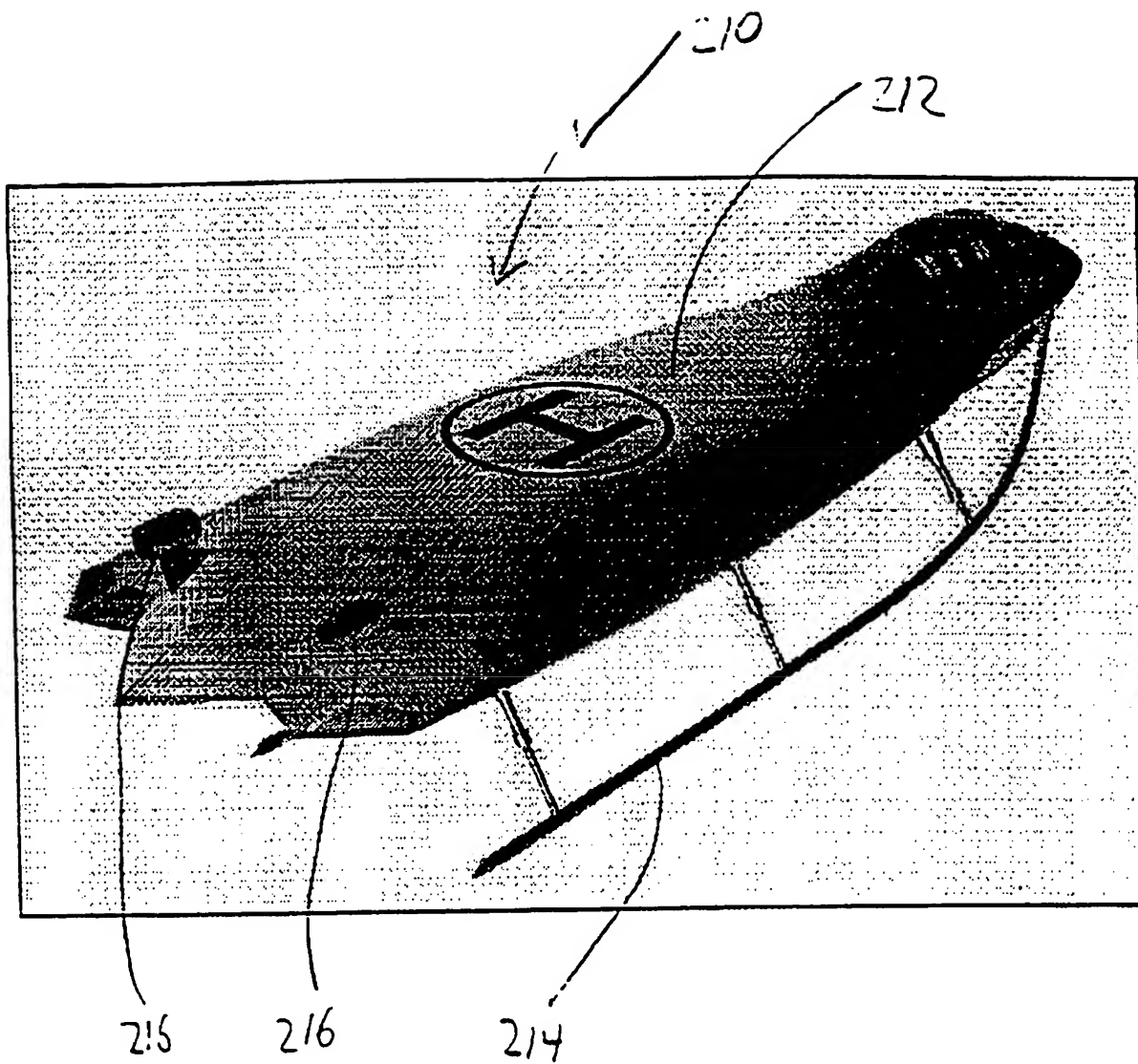


Fig.19

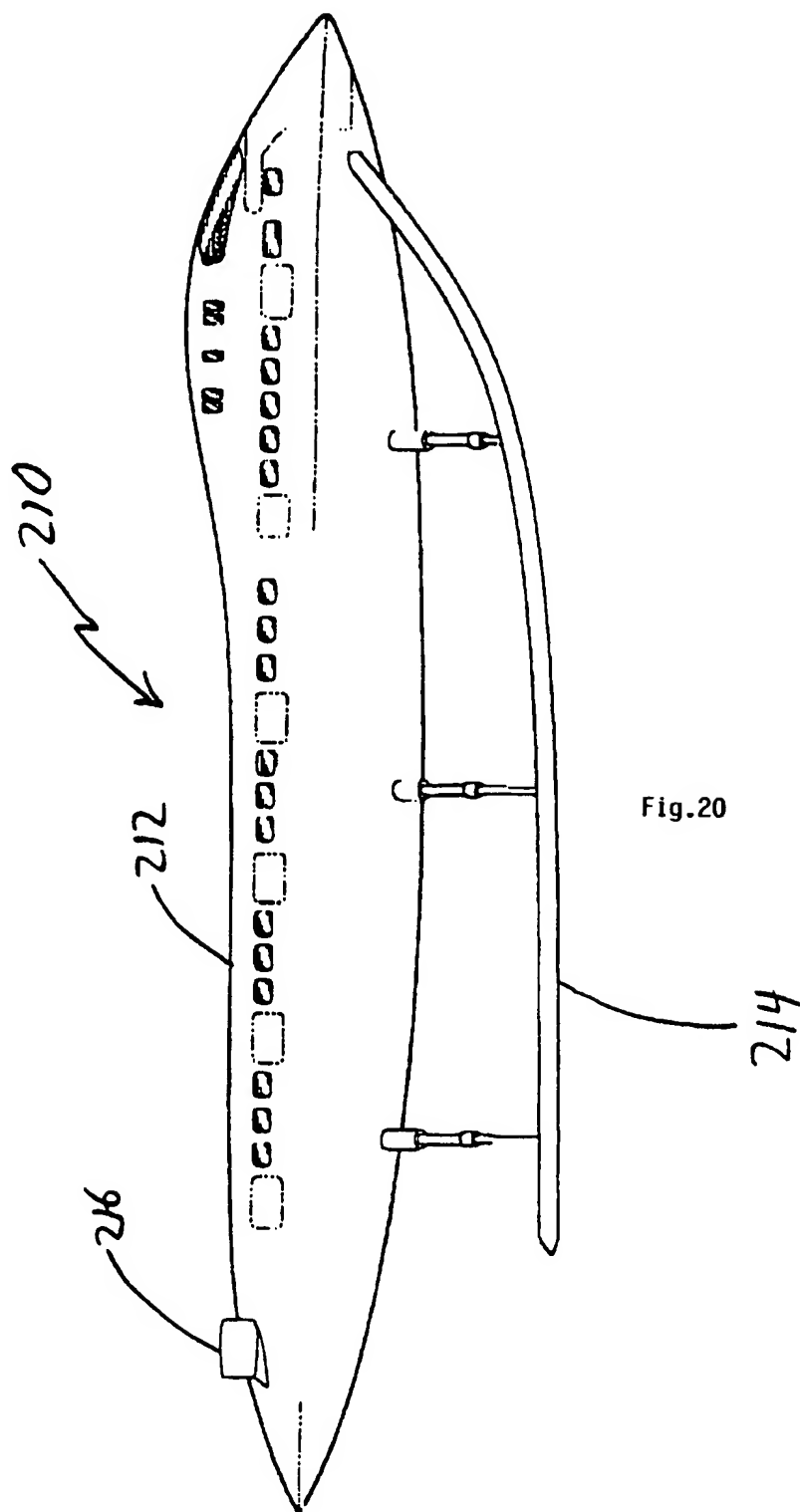


Fig. 20

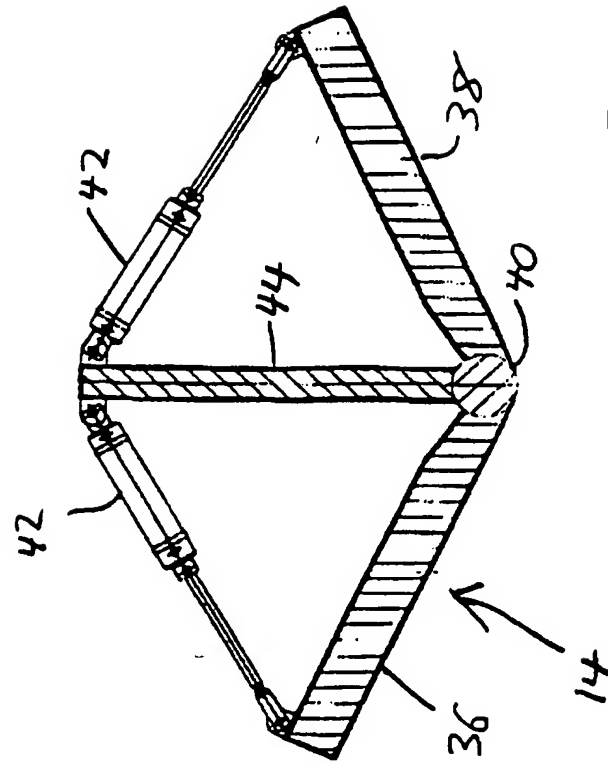


Fig. 22

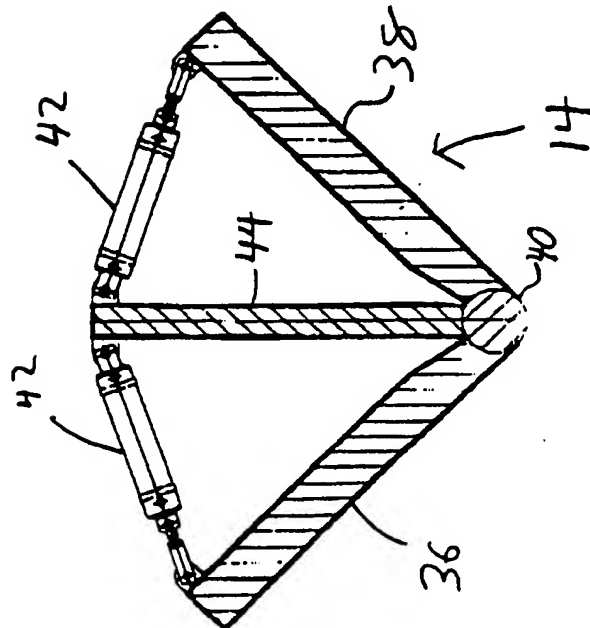


Fig.21

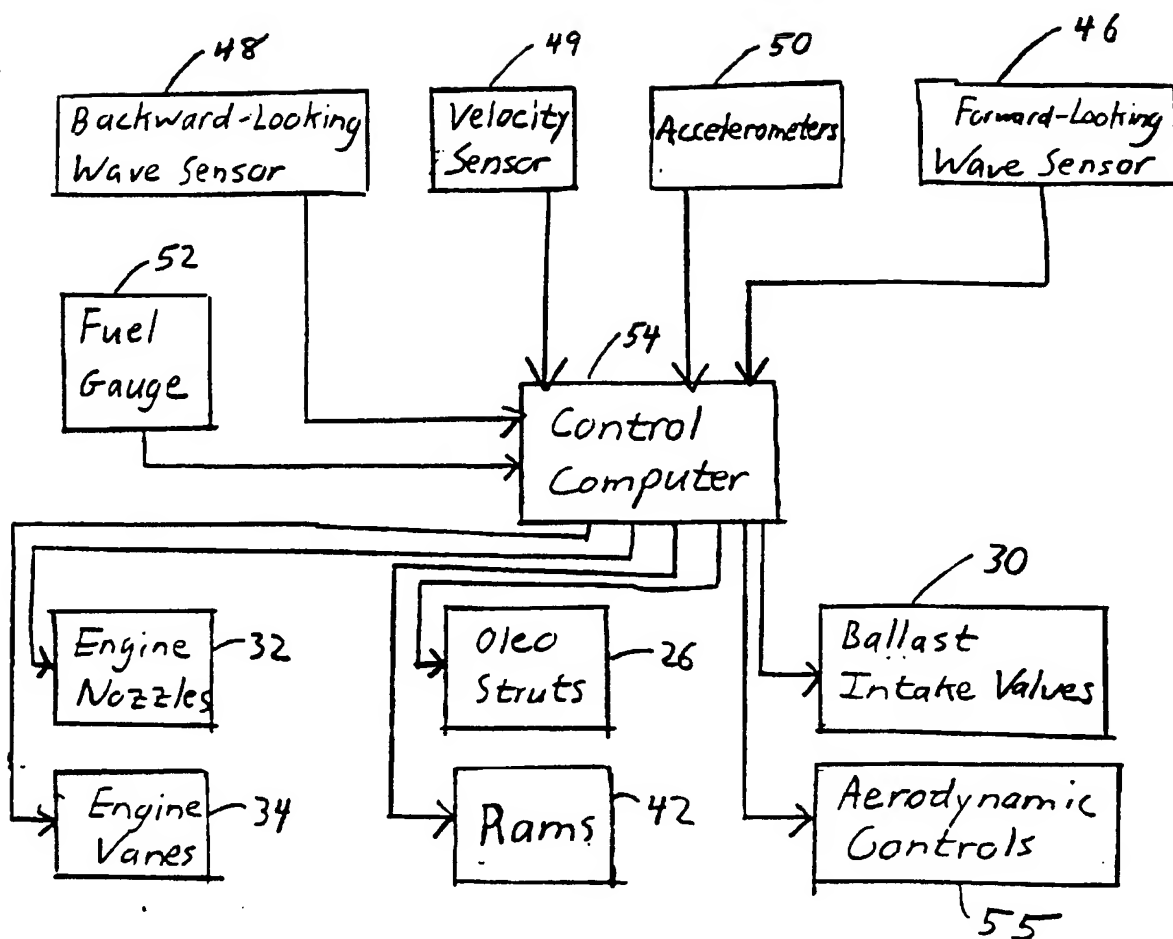
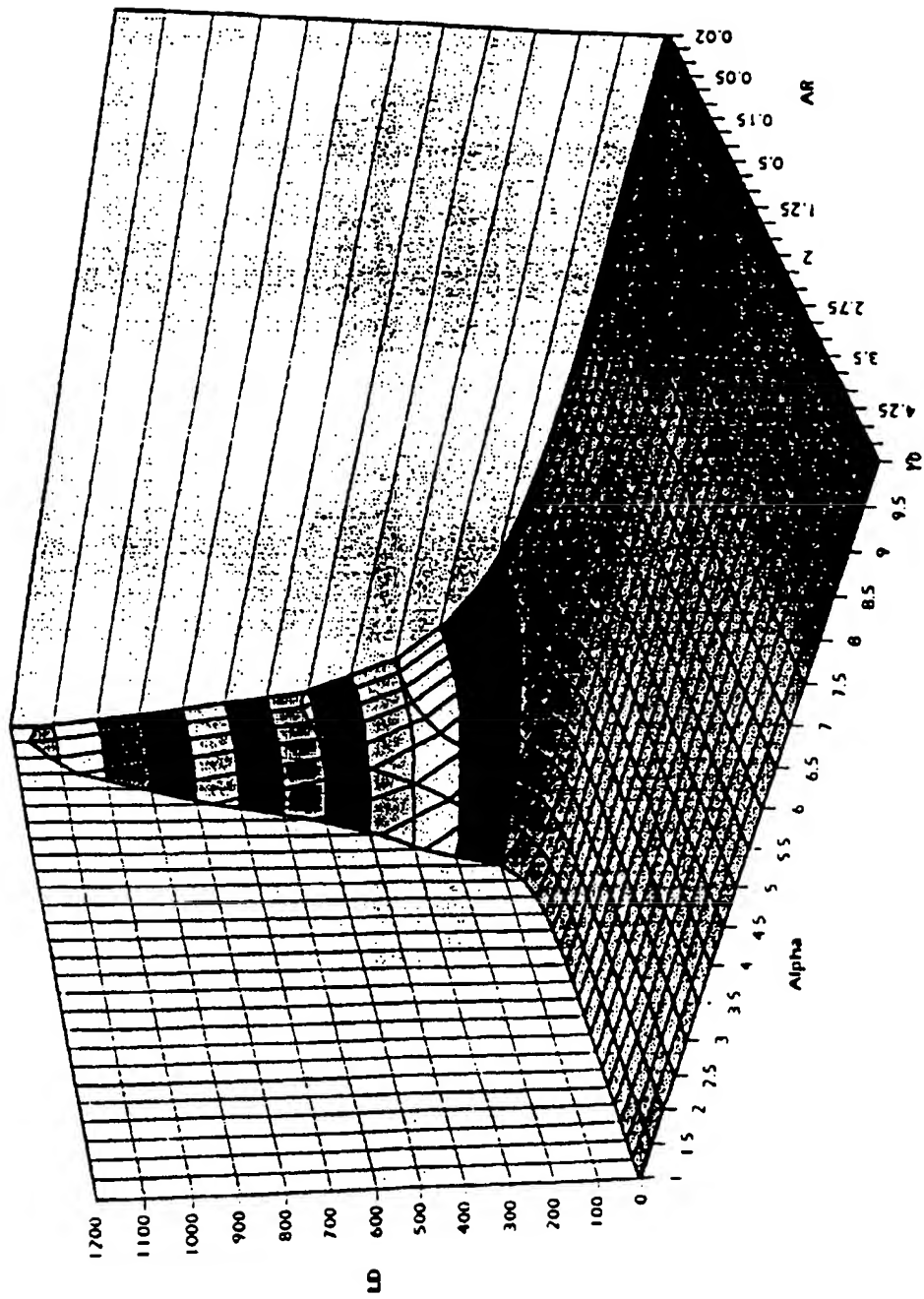


Fig.23

19/20

Fig.24

 λ_D vs AR & Alpha

Cd for Varying $Ap/V^{(2/3)}$ and Fn

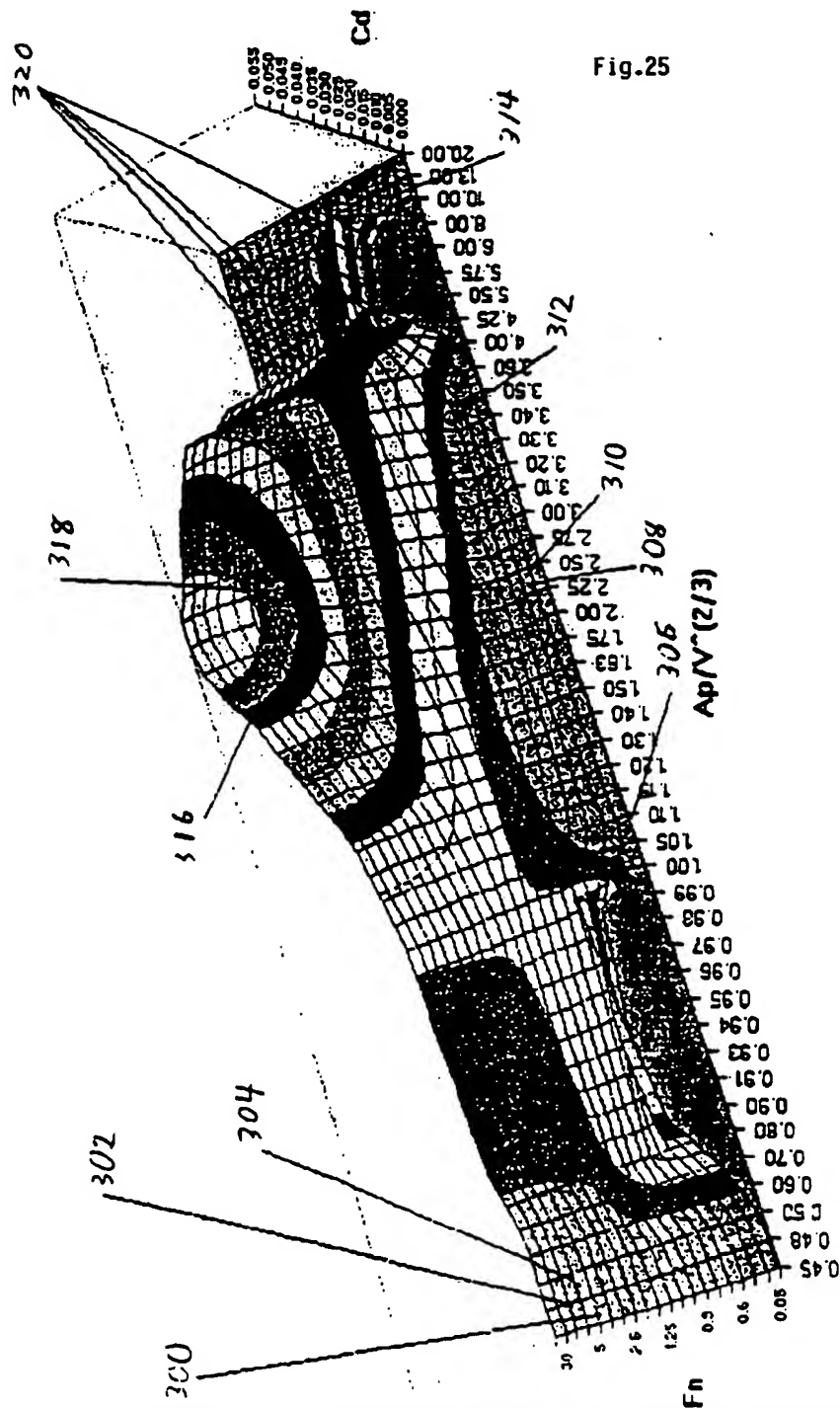


Fig.25

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US97/14987

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B63B 1/20

US CL :114/283

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 114/283,61,121,125,144e,270-278 440/38-42 D12/300,310

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
noneElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	JP 62-244,778 A (YUKIO KAJINO) 26 OCTOBER 1987 SEE ENTIRE PATENT	11,15, 21-24 ----- 1-3,5-8,12, 13,16- 20, 25, 26
X ----- Y	US 5,619,944 A (BAKER) 15 APRIL 1997, SEE ENTIRE PATENT	11,14,20 ----- 1-8
X	US 5,265,550 A (HARPER, JR.) 30 NOVEMBER 1993, SEE ENTIRE PATENT	52-55,58, 59
X	US 4,685,641 A (KIRSCH ET AL.) 11 AUGUST 1987, SEE ENTIRE PATENT	52-56

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

14 NOVEMBER 1997

Date of mailing of the international search report

12 DEC 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

ED SWINEHART

Telephone No. (703) 308-1113

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/149

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 2,647,709 A (DOOLITTLE ET AL.) 04 AUGUST 1953, SEE ENTIRE PATENT	27,28 ---- 29-31
Y	US 3,987,743 A (PENSEL) 26 OCTOBER 1976, SEE ENTIRE PATENT	9,10,19,20,25,26 29,30
Y	US 3,157,146 A (BILLIG) 17 NOVEMBER 1964, SEE ENTIRE PATENT	31

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US97/14987

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 27-31,33-51 and 57
because they relate to subject matter not required to be searched by this Authority, namely:

The specification is objected to as failing to provide an adequate written description of the control arrangement of the thrust vectoring system and planing element supports responsive to sensed wave conditions.
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

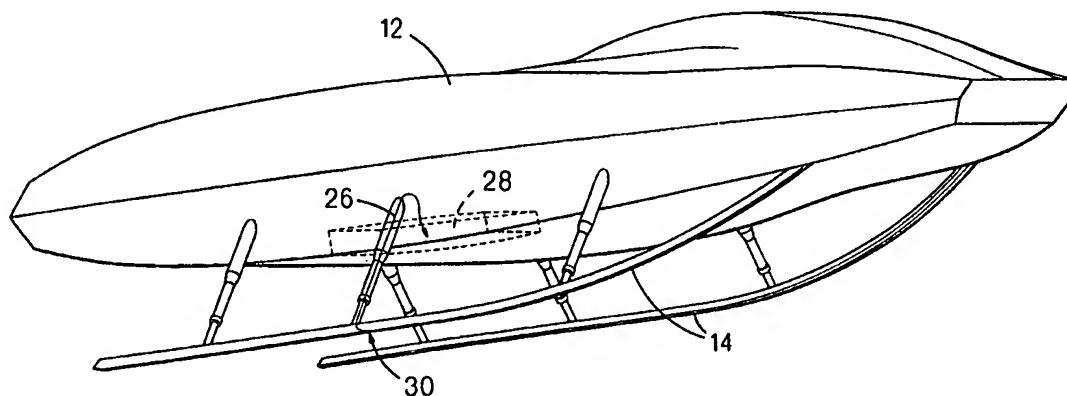
Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : B63B 1/20	A1	(11) International Publication Number: WO 98/08732 (43) International Publication Date: 5 March 1998 (05.03.98)
<p>(21) International Application Number: PCT/US97/14987</p> <p>(22) International Filing Date: 26 August 1997 (26.08.97)</p> <p>(30) Priority Data: 08/703,897 27 August 1996 (27.08.96) US</p> <p>(71) Applicant: NEWPORT TECHNOLOGIES, LTD. [US/US]; 1151 Hilltop Drive, Redding, CA 96003 (US).</p> <p>(72) Inventors: ROAKE, Richard, J.; 239A Eustis Avenue, New- port, RI 02840 (US). BAKER, Stephen, C.; 881 Fort Getty Road, Jamestown, RI 02835 (US).</p> <p>(74) Agent: MROSE, James, E.; Fish & Richardson, P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).</p>	<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i></p>	

(54) Title: HYDROSKIING MARINE VESSEL



(57) Abstract

A marine vessel includes a buoyant vessel body (12), a propulsive device, and at least one planing element (14). The planing element lifts the buoyant vessel body upward and out of contact with water throughout prolonged high-speed travel. The ratio of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds is less than 1. The length of the planing element is at least 20 times its breadth. At least one of a plurality of attachment mechanisms (26) attached between the planing element and the buoyant vessel body is controllably adjustable in length so as to adjust an angle of attack of the planing element with respect to water. A deadrise angle adjustment mechanism (42) controllably adjusts a deadrise angle of the planing element with respect to water. The buoyant vessel body includes a ballast tank (28), and ballast piping connects the ballast tank with a ballast intake valve (30).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

- 1 -

HYDROSKIING MARINE VESSELBackground of the Invention

This invention relates to marine vessels having
5 hydroskis and more particularly relates to hydroskiing
marine vessels capable of travel at very high speeds with
active control of pitch, yaw, and roll and dynamic
damping of impact loadings, wave loadings, and
vibrations.

10 Marine vessels may be fitted with hydroskis for
the purpose of lifting the buoyant vessel body out of
contact with water at sufficiently high speeds, due to
planing action of the hydroskis, thereby reducing
hydrodynamic drag. Such a marine vessel can be steered
15 by appropriate vectoring of the thrust of its propulsion
system. During hydroskiing operation the hydroskis are
displaced downwardly with respect to the buoyant vessel
body but during low-speed operation of the marine vessel
the hydroskis may be retracted upward such that the lower
20 surfaces of the hydroskis form part of the lower surface
of the hull of the marine vessel.

Summary of the Invention

One aspect of the invention features a marine
vessel that includes a buoyant vessel body, a propulsive
25 device attached to the buoyant vessel body to propel the
buoyant vessel body at high speed, and at least one
planing element attached to the buoyant vessel body. The
planing element or elements lift the buoyant vessel body
upward and out of contact with water throughout prolonged
30 high-speed travel of the marine vessel, by virtue of
lifting action due to planing. The planing element or
elements have a length and breadth that, when multiplied,
define a planing element area (A_p). Each of the planing
elements supports a weight that, when divided by mass
35 density of water, defines a volumetric equivalent of the
weight supported by the planing element (∇). The ratio

- 2 -

of the planing element area to the volumetric equivalent of the weight supported by the planing element raised to the power of two-thirds $A_p/(\nabla^{2/3})$ is less than 1.

Applicant believes that when $A_p/(\nabla^{2/3})$ is less
5 than 1 the coefficient of drag (C_d) due to planing of a hydroskiing marine vessel should be relatively low, given the froude number [$F_n = \text{speed}/(\text{gravitational acceleration} \times \text{hull length})^{1/2}$] at which such a vessel would be expected to operate. Because the coefficient of drag is low, such
10 a vessel should be able to operate at high speeds with high energy efficiency.

According to another aspect of the invention the length of each of the planing elements is at least 20 times the breadth of the planing element. Applicant
15 believes that the ratio of lift to drag (L/D) due to planing of a hydroskiing marine vessel is relatively high where the aspect ratio (AR) of breadth to length of the planing element is sufficiently low, assuming that the angle of attack (α) between the skis and the water is
20 also sufficiently low. The high lift to drag ratio enables the marine vessel to operate at high speeds with high energy efficiency.

According to another aspect of the invention there are a plurality of attachment mechanisms attached to the
25 planing element or elements and the buoyant vessel body. The attachment mechanisms have strength and rigidity sufficient to transmit lifting forces from the planing element or elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with
30 water. At least one of the attachment mechanisms is controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack (α) of the planing

- 3 -

element or elements with respect to the water during the high-speed travel.

The ability to adjust the angle of attack (α) of the planing element or elements with respect to the water is advantageous because lift is a function of the angle of attack. In particular, lift (L) is equal to $\frac{1}{2}\rho v^2 A_w (dC_L/d\alpha) \alpha (\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_w is the wetted area of the planing element at a given point in time, C_L is coefficient of lift, and β is the deadrise angle of the planing element. By appropriate adjustment of the angle of attack (α) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention provides a deadrise angle adjustment mechanism attached to the planing element or elements that controllably adjusts a deadrise angle (β) of the planing element or elements with respect to the water during the high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with the water. The ability to adjust the deadrise angle (β) of the planing element or elements with respect to the water is advantageous because lift is a function of the deadrise angle, as is discussed above. Thus, by appropriate adjustment of the deadrise angle (β) it is possible to maintain a substantially constant lift, in a planing condition, over a broad range of speeds.

Another aspect of the invention features one or more ballast tanks within the buoyant vessel body, one or more ballast intake valves, and ballast piping connecting the ballast tank or tanks with the ballast intake valve or valves. The ballast intake valve or valves controllably receive water during high-speed travel of the marine vessel to fill the ballast tank or tanks

- 4 -

through the ballast piping. The ballast tank or tanks make it possible to compensate for spent fuel with intake of water. By compensating for lost weight due to spent fuel it is possible to prevent undue lifting of the
5 buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel.

Another aspect of the invention features a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the
10 marine vessel and water waves, and a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system. The active vectoring of thrust
15 compensates for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

The sensor system may include, for example, an accelerometer that directly measures motion of the marine
20 vessel due to waves, or a wave sensor that detects water waves before the waves interact with the marine vessel, or both of the above combined with a sensor that measures the velocity of the marine vessel (from which the time of impact of a wave on the planing element or elements can
25 be determined). The active vectoring of thrust can provide a relatively smooth, stable ride of the marine vessel through turbulent water. The signal information from a wave sensor can include wave height information, in which case the control system can actively vector
30 thrust from the propulsive device so as to operate the marine vessel in a "platforming" mode if the wave height is relatively low and in a "contouring" mode if the wave height is relatively high. The buoyant vessel body travels a more uniform height with respect to mean water
35 level in the platforming mode than in the contouring mode

- 5 -

and travels a more uniform height with respect to actual water surface in the contouring mode than in the platforming mode.

According to another aspect of the invention at least one of the attachment mechanisms that transmit lifting forces from the planing element or elements to the buoyant vessel body includes a controllable dynamic force damper. The control system actively adjusts the controllable dynamic force damper in response to signal information from the sensor system to compensate for interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel. The active adjustment of the controllable dynamic force damper can provide a relatively smooth, stable ride of the marine vessel through turbulent water.

According to another aspect of the invention the planing elements have a configuration that permits the marine vessel to ground itself solely on the planing elements. Because the marine vessel can ground itself solely on the planing elements, the buoyant vessel body need not be constructed to withstand grounding contact between the buoyant vessel body itself and solid ground.

According to another aspect of the invention the attachment mechanisms are controllably adjustable to shift the planing element or elements between a high-speed position in which the planing element or elements are displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element or elements are displaced sideways relative to the buoyant vessel body so as to serve as fenders during docking maneuvers of the marine vessel. Because the planing element or elements can serve as docking fenders, the buoyant vessel body need not be constructed to withstand contact with other objects.

- 6 -

Numerous other features, objects, and advantages of the invention will become apparent from the following detailed description when read in connection with the accompanying drawings.

5 Brief Description of the Drawings

Figs. 1-3 are perspective drawings of a hydroski marine vessel in accordance with the invention.

Fig. 4 is an elevational front view of the vessel of Figs. 1-3, illustrating operating and retracted
10 positions of the hydroskis and operating and retracted positions of the take-off flaps.

Fig. 5 is an elevational side view of the vessel of Figs. 1-3, illustrating the range of available positions of the hydroskis due to active manipulation of
15 the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 6 is a perspective drawing of the vessel of Figs. 1-3 illustrating a ballast tank, ballast intake, and ballast piping.

20 Fig. 7 is an elevational side view of the vessel of Figs. 1-3 illustrating vertical thrust vectoring of the vessel.

Fig. 8 is a plan view of the vessel of Figs. 1-3 illustrating directional thrust vectoring of the vessel.

25 Figs. 9 and 10 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 11 is an elevational side view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

30 Fig. 12 is a plan view of the vessel of Figs. 9-10 illustrating internal components of the vessel.

Fig. 13 is an elevational side view of the vessel of Figs. 9-10 with the hydroski retracted for buoyant operation of the vessel.

- 7 -

Fig. 14 is an elevational side view of the vessel of Figs. 9-10 with the hydroski and take-off flaps in their operating positions.

Fig. 15 is an elevational side view of the vessel of Figs. 9-10, illustrating variation in the position of the hydroskis due to active manipulation of the angle of attack of the hydroskis or due to the damping function of oleo struts.

Fig. 16 is a set of elevational side views of one of the engines of the vessel of Figs. 9-10 illustrating vertical thrust vectoring of the vessel.

Fig. 17 is a set of plan views of the engines of the vessel of Figs. 9-10 illustrating directional thrust vectoring of the vessel.

Figs. 18 and 19 are perspective drawings of another hydroski marine vessel in accordance with the invention.

Fig. 20 is an elevational side view of the vessel of Figs. 18 and 19.

Fig. 21 is a cross-sectional drawing of a hydroski for use with the vessels of Figs. 1-20, adjusted for a high deadrise angle of the hydroski with respect to the water.

Fig. 22 is a cross-sectional drawing of the hydroski if Fig. 21 adjusted for a lower deadrise angle of the hydroski with respect to the water.

Fig. 23 is a block diagram of a system for active thrust vectoring and active force damping for use with the vessels of Figs. 1-20.

Fig. 24 is a chart of lift to drag ratio L/D of a planing element as a function of the aspect ratio AR of the planing element and the angle of attack α of the planing element.

- 8 -

Fig. 25 is a drag map of coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and as a function of froude number F_n .

Detailed Description

5 With reference to Figs. 1-3, marine vessel 10 includes buoyant vessel body 12 and hydroskis 14, upon which buoyant vessel body 12 travels at high speeds of between 158 and 250 knots (200 knots is normal). Engines 16, which may be, for example, Pratt and Whitney 4000
10 turbofan engines in a thrust class of about 90,000 lbs of thrust per engine, provide propulsive force to buoyant vessel body 12 while hydroskis 14 lift buoyant vessel body 12 upward and such that the buoyant vessel body is out of contact with water. At 200 knots, engines 16 are
15 typically at 50-80% of available thrust. Alternatively, air propellers, ducted fans, turbines, turbofans, or other fluid momentum imparting devices may be used. Hydroskis 14 are non-buoyant and made of titanium or carbon fiber, but in alternative embodiments buoyant
20 hydroskis or hydroskis made of other materials may be used. The dynamic lift from the hydroskis is sufficient to maintain the whole vessel in operating trim with the hydroskis planing on the surface of the water and cutting through waves.

25 Buoyant vessel body 12 is 410 feet long and has a fully-loaded weight of about 10,000-15,000 tons. Hydroskis 14 have a total length of 301.12 feet and a breadth of 4.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.0158 ("aspect
30 ratio" as used herein refers to the breadth of a planing element divided by its length, regardless of whether the total length is wetted). As is illustrated in Fig. 24, taken from an article by Kerwin, Mandel, and Lewis (M.I.T.), Journal of Ship Research, 1972, the lift to
35 drag ratio L/D of the hydroskis is relatively high when

- 9 -

the aspect ratio AR is low and the angle of attack α of the hydroskis (the longitudinal trim angle of the hydroskis relative to the water) is low (all points on this graph less than an aspect ratio of 0.25 are interpolated). In general, the length of the skis should be about 72-80% of the length of the boat and the skis should have a depth of about 8-12% of the length of the boat.

The planing element area A_p of each of the hydroskis is 1433 square feet ("planing element area" as used herein refers to the total length of a planing element multiplied by its breadth, regardless of whether the total length is wetted). Because the planing element area is relatively small compared to the dimensions of the vessel, the ratio of the planing element area to the volumetric equivalent of the weight supported by each planing element (one-half the total weight of the vessel) raised to the power of two-thirds [$A_p/(\nabla^{2/3})$] is less than 1. Fig. 25 shows the coefficient of drag C_d of a marine vessel as a function of $A_p/(\nabla^{2/3})$ and froude number F_n [speed/(gravitational acceleration x hull length)^{1/2}]. Reference number 300 on the drag map represents the vessel of Figs. 1-8 loaded to 15,000 tons and travelling at 165 knots. It can be seen that the coefficient of drag C_d is relatively low when $A_p/(\nabla^{2/3})$ is less than 1 and at froude numbers at which such a vessel would be expected to operate. More preferably, $A_p/(\nabla^{2/3})$ is less than 0.9, and even more preferably, less than 0.6. Below is a list of reference numbers on the drag map of Fig. 25 and the items they represent:

- 300: vessel of Figs. 1-8 at 15 kT and 165 kts;
- 302: 6,000 lb. Unlimited Hydroplane at 200 kts
(temporary condition only on the order of a few seconds);
- 304: 180 lb. waterskier at 35 kts;
- 306: 60 kT Great Lakes Ore Carrier at 25 kts;

- 10 -

- 308: 9 kT Destroyer at 35 kts;
- 310: Torpedo 3 Human-Powered Sub at 6 kts;
- 312: 800 kT Supertanker at 25 kts;
- 314: IACC Yacht at 10 kts;
- 5 316: ADCAP Torpedo at 55 kts;
- 318: Mk50 Adv. Light Torpedo at 50 kts;
- 320: Clements & Blount Planning Boat.

Due to the minimization of hydrodynamic drag on the marine vessel, at most points in the high-speed operating
10 range aerodynamic drag is substantially greater than hydrodynamic drag.

Referring to Fig. 4, during low-speed operation of the marine vessel hydroskis 14 are positioned as shown in dashed lines in order to reduce draft for entry into
15 areas of water too shallow for the marine vessel to enter with the hydroskis in the operating position, in order to reduce drag while the marine vessel is travelling at buoyant or displacement speeds, and in order for the hydroskis to serve as "fenders" during docking maneuvers.
20 During high-speed operation the hydroskis are positioned as shown in solid lines. The static water line during low-speed operation is represented by horizontal line 18, and the running water line during high-speed operation is represented by horizontal line 20. Hydroskis 14 may also
25 be positioned in an intermediate position to permit grounding of the marine vessel on the hydroskis alone. The bottom of the buoyant vessel body can consequently have a relatively light construction.

In preparation for "take-off" of the marine vessel
30 the hydroskis are moved to the high-speed position, and take-off flaps 22 are deployed in the operating position shown in solid lines in Fig. 4 (the flaps are also shown in the operating position in Fig. 2). The vessel accelerates at a pitch of about 6 degrees (with the skis
35 pitched at 1.8 degrees relative to the vessel) in order

- 11 -

to maximize the lift coefficient. At about 40 or 45 knots the buoyant vessel body is lifted entirely out of contact with the water. As the vessel accelerates between 50 and 135 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 4, and the vessel slowly pitches down from 6 degrees to 0 degrees. The take-off flaps provide additional lift necessary to push the buoyant vessel body up and out of contact with the water below 135 knots.

10 With reference to Fig. 5, hydroskis 14 are attached to buoyant vessel body 12 by pivot 24 and oleo struts 26, which may be 2,000-ton rams, 45 feet in length and 8 feet in diameter, that use hydraulic oil, air, or rheologic fluid as a damping medium for the absorption or
15 reduction of vibrations and shock loadings associated with acoustical noise, impact loadings or wave loadings or any other loadings on hydroskis 14. The dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroskis 14. This angle of
20 attack can be adjusted in order to control the lift provided by the hydroskis, which is equal to $\frac{1}{2}\rho v^2 A_w (dC_L/d\alpha) \alpha (\cos\beta)$, where ρ is the density of water, v is velocity of the marine vessel, A_w is the wetted area of the planing element at a given point in time, C_L is
25 coefficient of lift, and β is the deadrise (or dihedral) angle of the hydroskis. Also, oleo struts 26 can be dynamically controlled in order to compensate for unwanted forces experienced by the marine vessel due to interactions of the vessel with waves. Other hydraulic,
30 electric or mechanical devices may be substituted for oleo struts 26. The oleo struts are also used to move the hydroskis between the high-speed position (solid lines in Fig. 4), the low-speed position (dashed lines in Fig. 4), and the intermediate "grounding" position.

- 12 -

Fig. 6 shows a ballast tank 28 in buoyant vessel body 12, and a ballast intake valve 30 is provided on one of hydroskis 14 to enable ballast tank 28 to be filled with water through ballast piping in oleo strut 26.

5 Ballast tank 28 is actually one of a number of such ballast tanks within the buoyant vessel body, and ballast intake valve 30 is one of a number of such ballast intake valves on both hydroskis 14. As fuel is consumed by the marine vessel, ballast intake can be controlled by
10 controlling the ballast intake valves so as to compensate for the lost weight with intake of water into the ballast tanks. This prevents undue lifting of the buoyant vessel body due to planing, which would result in inefficient operation of the marine vessel due to a decrease in the
15 length of the water line and a corresponding increase in drag. A 10,000 ton boat might burn about 1,500 tons of fuel during a typical voyage.

With reference to Figs. 7 and 8, steering of the marine vessel can be accomplished through thrust
20 vectoring of engines 16. The engines include rotatable divergent/convergent nozzles 32 in the exhaust plenum that can be adjusted to vector thrust upward up to about 20°, downward up to about 20°, or in a neutral position. Similarly, engines 16 also include rotatable vanes 34 in
25 the exhaust plenum that can be adjusted to vector thrust to port up to about 20°, to starboard up to about 20°, or in a neutral position. In alternative embodiments the thrust provided by an engine or propulsive device can be vectored by other variable-geometry vanes, paddles,
30 nozzles or other fluid momentum vectoring devices situated in the thrust stream and capable of being rotated about the desired axis to direct the thrust stream in a direction appropriate to the intended vectoring. In one such design a cone of interleaved
35 petals is provided that can be directed up to about 20°

- 13 -

off of center in any given direction, the cone having a nozzle whose size can be varied by appropriate adjustment of the petals. Thrust vectoring can alternatively be accomplished by physical movement or rotation of the propulsive device itself.

Referring to Figs. 21 and 22, each hydroski 14 includes surface elements 36 and 38 pivotally connected about pivot 40. Rams 42, which may be hydraulic, air, or rheologic fluid-damped struts, are connected between surface elements 36 and 38 and a central vertical strut 44. Rams 42 can be adjusted to vary the deadrise angle β of hydroski 14 between a high value of 60 degrees or higher with respect to horizontal and a low value of 0 degrees with respect to horizontal and anywhere in-between. Figs 21 and 22 show two different configurations of the hydroski corresponding to two different deadrise angles. As is discussed above the lift provided by the hydroskis is proportional to the cosine of the deadrise angle β of the hydroskis, and thus lift can be controlled by controlling the deadrise angle through rams 42. At takeoff, the deadrise angle should be at 0 degrees, and at very high speed the deadrise angle should be high. Other hydraulic, electric or mechanical devices may be substituted for rams 42. The deadrise adjustment feature is the primary mechanism of compensation for overspeed or underspeed, which can result from interactions between the vessel and waves, aerodynamic forces, or decelerations due to maneuvering of the vessel, because this feature makes it possible to very easily relax or increase lift from the hydroskis. This ensures that the waterline length on the hydroskis stays at the correct value, and thus the center of lift of the vessel does not move backward or forward.

With reference to Fig. 23, the marine vessel is fitted with forward-looking wave sensor 46, backward-

- 14 -

looking wave sensor 48, velocity sensor 49, accelerometers 50, and fuel gauge 52, all of which transmit signal information to control computer 54. Based on this signal information the control computer
5 actively controls nozzles 32 and vanes 34 of the engines, oleo struts 26 and rams 42, ballast intake valves 30, and aerodynamic controls 55 (including ailerons for roll control, elevons for pitch control, and speed brakes for speed reduction). Wave sensors 46 and 48 may include
10 RADAR or millimeter-wave RADAR or LIDAR technology for determining the height, distance, and velocity of waves. Accelerometers 50 may be laser accelerometers.

In particular, in response to undesired accelerations of the marine vessel sensed by
15 accelerometers 50 due to interactions between the vessel and waves, or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity sensor 49, control computer 54 actively vectors
20 thrust from the engines in an appropriate direction and amount so as to compensate for undesired movement of the vessel. The undesired acceleration may result in pitch (rotation about a transverse axis), yaw (rotation about a vertical axis), roll (rotation about a longitudinal
25 axis), or change in velocity, or any combination thereof. In addition, control computer 54 can adjust aerodynamic controls 55 in response to undesired motion of the vessel.

The control computer 54 also, in response to
30 undesired accelerations of the marine vessel sensed by accelerometers 50 (pitch, yaw, roll, change in velocity), or in response to predicted impacts of waves on the hydroskis based on information provided by wave sensor 46 combined with vessel velocity as measured by velocity
35 sensor 49, actively adjusts oleo struts 26 and the

- 15 -

response rate of these struts so as to actively damp or reduce impact loadings and wave loadings, including wave impact loadings. Oleo struts 26 also inherently damp or reduce vibrations and loadings wholly apart from computer control. Immediately prior to a wave hit on one of the hydroskis, control computer 54 creates a differential pulse or force in one or more of oleo struts 26 in a direction opposite to the anticipated pulse created by the wave hit. Once the wave has hit the hydroski, control computer 54 softens residual forces in oleo struts 26, measured by accelerometers 50, in a similar manner. If the residual forces are directed upward, oleo struts 26 are caused to pull the hydroski upward; if the residual forces are directed downward, the oleo struts are caused to pull the hydroski downward.

Control computer 54 also adjusts oleo struts 26 to vary the angle of attack of the hydroskis and adjusts rams 42 to vary the deadrise angle of the hydroskis in order to provide a lift that is appropriate for a given speed of the marine vessel as measured by velocity meter 49. Thus, the hydroskis are capable of maintaining appropriate lift in a planing condition over a broad range of speeds. This is important because if the lift is too high the waterline length will decrease and consequently drag will increase.

During normal operation the marine vessel operates in a platforming mode of operation in which the buoyant vessel body travels at a constant height with respect to the mean water level. This is possible because thrust vectoring can overcome any pitching forces at a given speed where the wave height does not exceed the difference between flat water normal running trim and the bottom of the buoyant vessel body (i.e., where the waves will not crash into the buoyant vessel body). Thus, the

- 16 -

buoyant vessel body need not be constructed to withstand high-speed impacts from waves.

Furthermore, if the wave height detected by wave sensor 46 is such that the wave crests would be close to five feet from the bottom of the buoyant vessel body (in the case of a 410-foot vessel), or if an adverse weather report is received, then control computer 54 can shift from the standard platforming mode of operation to a contouring mode of operation, in which the buoyant vessel body travels at a constant height with respect to the actual water surface (or at least a more constant height with respect to the actual water surface than in the platforming mode), in order to prevent impact between the waves and the buoyant vessel body. Depending on the height of the waves, the control computer 54 may operate in an intermediate mode of operation in which contouring occurs only to the extent necessary to keep the crests of the waves more than five feet below the bottom of the buoyant vessel body. In other words, the skis go through the waves in this intermediate mode, but the marine vessel is actively pitched up and down by active thrust vectoring sufficiently to ensure that the bottom of the buoyant vessel body will never impact a wave. The contouring is accomplished by active thrust vectoring of engines 16. Also, during the contouring or intermediate mode of operation, control computer 54 causes the marine vessel to travel at an angle with respect to the waves. In particular, if the marine vessel is unable or might be unable to travel over a particular large wave having a height greater than a threshold value, the control computer causes the marine vessel to make a sharp pitching turn. The severity of the turn is proportional to the greater of two limiting factors: 1) the amount of time remaining before the particular large wave could impact the vessel, or 2) the size of the large wave,

- 17 -

which determines the amount of work required and hence the amount of time required, once the wave has reached the vessel, for the vessel to execute a contouring maneuver (contouring over the large wave) such that the buoyant vessel body does not impact the wave. The contouring and intermediate modes of operation are essentially emergency modes.

Control computer 54 can maintain a constant vessel weight by causing water to be introduced into the ballast tanks through ballast intake valves 30 in response to information received from fuel gauge 52 concerning fuel consumption. The maintenance of a constant vessel weight and a constant lift ensures a near constant waterline length of the marine vessel throughout the speed range of high-speed operation, which in turn minimizes drag.

During grounding of the marine vessel on the hydroskis, the control computer controls oleo struts 26 in response to information received from accelerometers 50 and forward-looking and backward-looking wave sensors 46 and 48, in order to compensate for undesired forces due to interaction between the marine vessel and waves. If a wave hit on the port side of the vessel is imminent, the oleo struts on the starboard side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the starboard side. Likewise, if a wave hit on the starboard side of the vessel is imminent, the oleo struts on the port side are stiffened and then relaxed slowly so as to absorb energy and to allow the vessel to shift gently toward the port side.

With reference to Figs. 9-12, another embodiment of a marine vessel 110 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 112 and a single hydroski 114, upon which

- 18 -

buoyant vessel body 112 travels at high speeds in the range of 300 knots. Engines 116 are in a thrust class of about 750 lbs of thrust per engine.

Buoyant vessel body 112 is 34 feet long and has a fully-loaded weight of about 6.26 tons. Hydroski 114 has a length of 24.97 feet and a breadth of 0.76 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroski is 0.03. The planing element area A_p of the hydroski is 18.98 square feet. Reference number 302 on the drag map of Fig. 25 represents the vessel of Figs. 9-17 loaded to 10,000 tons and travelling at 200 knots.

During low-speed operation of the marine vessel hydroski 114 is positioned as shown in Fig. 13. During high-speed operation the hydroski is positioned as shown in Fig. 14. The static water line during low-speed operation is represented by horizontal line 118, and the running water line during high-speed operation is represented by horizontal line 120.

In preparation for "take-off" of the marine vessel the hydroski is moved to the high-speed position, and take-off flaps 122, which are mounted on the wings of the vessel, are deployed in the operating position shown in solid lines in Fig. 14. As the vessel accelerates between 5 and 50 knots, the take-off flaps are slowly retracted to the position shown in dashed lines in Fig. 13. Take-off flaps 122 assist in stability during "take-off" and "landing" of the single-hydroski marine vessel.

Because the marine vessel has a single hydroski 114 it is highly maneuverable and capable of relatively sharp cornering. As thrust vectoring or aerodynamic controls or both cause the marine vessel to turn, the lift forces provided by the hydroski pushes the vessel into the turn in a banking maneuver.

With reference to Fig. 15, hydroski 114 is attached to buoyant vessel body 112 by pivot 124 and oleo

- 19 -

struts 126. Solid and dashed lines represent the range of positions of the longitudinal trim angle or angle of attack of hydroski 114.

With reference to Figs. 16 and 17, engines 116 include rotatable nozzles 132 that can be adjusted to vector thrust upward, downward, or in a neutral position. Similarly, engines 116 also include rotatable vanes 134 that can be adjusted to vector thrust to port, to starboard, or in a neutral position.

Referring to Figs. 18-20, another embodiment of a marine vessel 210 operates in the same manner as marine vessel 10 of Figs. 1-8 except as otherwise indicated below. The marine vessel includes buoyant vessel body 212 and a hydroskis 214, upon which buoyant vessel body 212 travels at high speeds of between 125 and 250 knots. Engines 216 are in a thrust class of about 90,000 lbs of thrust per engine.

Buoyant vessel body 212 is 300 feet long and has a fully-loaded weight of about 1,800 tons. Hydroskis 214 have a length of 220.3 feet and a breadth of 2.14 feet. Thus, the aspect ratio (AR) of the breadth to the length of the hydroskis is 0.097. The planing element area A_p of the hydroskis is 942.88 square feet. Reference number 304 on the drag map of Fig. 25 represents the vessel of Figs. 18-20 loaded to 1,500 tons and travelling at 165 knots.

There have been described novel and improved apparatus and techniques for marine vessel hydroskiing. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concept. For example, it is possible to construct other marine vessels according to the invention having different dimensions and performance parameters, e.g., vessels with more powerful engines that

- 20 -

travel at substantially greater speeds than those described herein.

- 21 -

What is claimed is:

1. A marine vessel comprising:
 - a buoyant vessel body;
 - a propulsive device attached to the buoyant vessel
 - 5 body to propel the buoyant vessel body at high speed; and
 - at least one planing element attached to the
 - buoyant vessel body so as to lift the buoyant vessel body
 - upward and out of contact with water throughout prolonged
 - high-speed travel of the marine vessel by virtue of
 - 10 lifting action due to planing;
 - the planing element having a length and breadth
 - that, when multiplied, define a planing element area;
 - the planing element supporting a weight that, when
 - divided by mass density of water, defines a volumetric
 - 15 equivalent of the weight supported by the planing
 - element;
 - the ratio of the planing element area to the
 - volumetric equivalent of the weight supported by the
 - planing element raised to the power of two-thirds being
 - 20 less than 1.
2. The marine vessel of claim 1 wherein the ratio
- of the planing element area to the volumetric equivalent
- of the total weight of the marine vessel raised to the
- power of two-thirds is less than 0.9.
- 25 3. The marine vessel of claim 2 wherein the ratio
- of the planing element area to the volumetric equivalent
- of the total weight of the marine vessel raised to the
- power of two-thirds is less than 0.6.
- 30 4. The marine vessel of claim 1 wherein
- there are a plurality of planing elements attached
- to the buoyant vessel body so as to lift the buoyant
- vessel body upward and out of contact with water during

- 22 -

high-speed travel of the marine vessel, by virtue of lifting action due to planing;

each planing element has a length and breadth that, when multiplied, defines a planing element area;

5 each planing element supports a weight that, when divided by mass density of water, defines a volumetric equivalent of the weight supported by the planing element;

10 the weight supported by each planing element is a portion of total weight supported by the plurality of planing elements; and

the ratio of the planing element area of each of the planing elements to the volumetric equivalent of the weight supported by the planing element raised to the
15 power of two-thirds is less than 1 throughout prolonged high-speed travel of the marine vessel in which the buoyant vessel body is lifted upward and out of contact with water.

5. The marine vessel of claim 1 wherein the
20 propulsive device is attached directly to the buoyant vessel body.

6. The marine vessel of claim 1 wherein the high speed is greater than 100 knots.

7. The marine vessel of claim 6 wherein the high
25 speed is greater than 150 knots.

8. The marine vessel of claim 1 wherein the prolonged high-speed travel has a duration on the order of one or more hours.

9. The marine vessel of claim 1 wherein the at
30 least one planing element is buoyant.

- 23 -

10. The marine vessel of claim 1 wherein the at least one planing element is non-buoyant.

11. A marine vessel comprising:

a buoyant vessel body;

5 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed; and at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed
10 travel of the marine vessel, by virtue of lifting action due to planing;

the planing element having a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

15 12. The marine vessel of claim 11 wherein the length of the planing element is at least 40 times the breadth of the planing element.

13. The marine vessel of claim 12 wherein the length of the planing element is at least 100 times the
20 breadth of the planing element.

14. The marine vessel of claim 11 wherein there are a plurality of planing elements attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during
25 high-speed travel of the marine vessel, by virtue of lifting action due to planing; and

each planing element has a length and a breadth such that the length of the planing element is at least 20 times the breadth of the planing element.

- 24 -

15. The marine vessel of claim 11 wherein the propulsive device is attached directly to the buoyant vessel body.

16. The marine vessel of claim 11 wherein the
5 high speed is greater than 100 knots.

17. The marine vessel of claim 16 wherein the high speed is greater than 150 knots.

18. The marine vessel of claim 11 wherein the prolonged high-speed travel has a duration on the order
10 of one or more hours.

19. The marine vessel of claim 11 wherein the at least one planing element is buoyant.

20. The marine vessel of claim 11 wherein the at least one planing element is non-buoyant.

15 21. A hydroski assembly comprising:
a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and
20 a plurality of attachment mechanisms attached to the hydroski and constructed for attachment to the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the hydroski to the buoyant vessel body to
25 lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms being controllably adjustable in length during the high-speed travel of the marine vessel in which the buoyant vessel

- 25 -

body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

22. The hydroski assembly of claim 21 wherein the
5 attachment mechanism that is controllably adjustable in length comprises a strut.

23. The hydroski assembly of claim 22 wherein the strut is an oleo strut that is controllably adjustable in length.

10 24. The hydroski assembly of claim 21 wherein one of the attachment mechanisms other than the attachment mechanism that is controllably adjustable in length comprises a pivot mechanism constructed for direct
15 attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

25. The hydroski assembly of claim 21 wherein the hydroski is buoyant.

26. The hydroski assembly of claim 21 wherein the hydroski is non-buoyant.

20 27. A hydroski assembly comprising:
a hydroski defining a planing surface to lift a buoyant vessel body of a marine vessel upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing; and
25 a deadrise angle adjustment mechanism attached to the hydroski and constructed to controllably adjust a deadrise angle of the hydroski with respect to the water during the high-speed travel of the marine vessel in

- 26 -

which the buoyant vessel body is lifted upward and out of contact with the water.

28. The hydroski assembly of claim 27 wherein:
the hydroski comprises a plurality of surface
5 elements extending the length of the hydroski, the
plurality of surface elements being pivotally attached to
each other along the length of the hydroski about at
least one pivot; and

the deadrise angle adjustment mechanism comprises
10 a plurality of struts, attached to the surface elements
of the hydroski, that are controllably adjustable in
length during the high-speed travel of the marine vessel
in which the buoyant vessel body is lifted upward and out
of contact with the water, so as to adjust an angle
15 between the surface elements about the pivot to vary a
deadrise angle of the hydroski with respect to the water
during the high-speed travel.

29. The hydroski assembly of claim 27 wherein the
hydroski is buoyant.

20 30. The hydroski assembly of claim 27 wherein the
hydroski is non-buoyant.

31. The hydroski assembly of claim 27 further
comprising a plurality of attachment mechanisms attached
to the hydroski and constructed for attachment to the
25 buoyant vessel body, the attachment mechanisms having
strength and rigidity sufficient to transmit lifting
forces from the hydroski to the buoyant vessel body to
lift the buoyant vessel body upward and out of contact
with water, at least one of the attachment mechanisms
30 being controllably adjustable in length during the high-
speed travel of the marine vessel in which the buoyant

- 27 -

vessel body is lifted upward and out of contact with the water, so as to adjust an angle of attack of the hydroski with respect to the water during the high-speed travel.

32. A marine vessel comprising:

- 5 a buoyant vessel body;
- a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body
- 10 upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action due to planing;
- at least one ballast tank within the buoyant vessel body;
- 15 at least one ballast intake valve; and
- ballast piping connecting the ballast tank with the ballast intake valve;
- the ballast intake valve being arranged to controllably receive water during high-speed travel of
- 20 the marine vessel to fill the ballast tank through the ballast piping.

33. A marine vessel comprising:

- a buoyant vessel body;
- a propulsive device attached to the buoyant vessel
- 25 body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action
- 30 due to planing;
- a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

- 28 -

a control system connected to the sensor system and to the propulsive device and configured to actively vector thrust from the propulsive device in response to the signal information from the sensor system to
5 compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

34. The marine vessel of claim 33 wherein the sensor system comprises at least one accelerometer that
10 directly measures motion of the marine vessel due to waves.

35. The marine vessel of claim 33 wherein the sensor system comprises a wave sensor that detects water waves, and wherein the signal information provided by the
15 sensor system comprises information from which anticipated motion of the marine vessel due to water waves can be predicted.

36. The marine vessel of claim 33 wherein the propulsive device comprises a plurality of independent
20 propulsion units controlled by the control system.

37. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises pitch motion.

38. The marine vessel of claim 33 wherein the
25 undesired motion of the marine vessel comprises yaw motion.

39. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises roll motion.

- 29 -

40. The marine vessel of claim 33 wherein the undesired motion of the marine vessel comprises a change in velocity.

41. The marine vessel of claim 33 further
5 comprising a directional control system connected to the propulsive device to actively vector thrust from the propulsive device to steer the marine vessel.

42. The marine vessel of claim 33 wherein the signal information pertaining to interaction between the
10 marine vessel and the water waves comprises wave height information, and wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in a platforming mode if the wave height is relatively low and in a contouring
15 mode if the wave height is relatively high, the buoyant vessel body travelling a more uniform height with respect to mean water level in the platforming mode than in the contouring mode and travelling a more uniform height with respect to actual water surface in the contouring mode
20 than in the platforming mode.

43. The marine vessel of claim 42 wherein the control system is configured to actively vector thrust from the propulsive device so as to operate the marine vessel in an intermediate mode if the wave height is
25 intermediate, the buoyant vessel body, in the intermediate mode, travelling a more uniform height with respect to mean water level than in the contouring mode but a less uniform height with respect to mean water level than in the platforming mode, and travelling a more
30 uniform height with respect to actual water surface than in the platforming mode but a less uniform height with

- 30 -

respect to actual water surface than in the contouring mode.

44. A marine vessel comprising:

a buoyant vessel body;

5 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed
10 travel of the marine vessel, by virtue of lifting action due to planing;

a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity
15 sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

at least one of the attachment mechanisms comprising a controllable dynamic force damper;

20 a sensor system attached to the buoyant vessel body to provide signal information pertaining to interaction between the marine vessel and water waves;

a control system connected to the sensor system and to the controllable dynamic force damper and
25 configured to actively adjust the controllable dynamic force damper in response to the signal information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the high-speed travel of the marine vessel.

30 45. The marine vessel of claim 44 wherein the controllable dynamic force damper dynamically dampens loadings and vibrations experienced by the planing

- 31 -

element apart from adjustment of the controllable dynamic force damper by the control system.

46. The marine vessel of claim 44 wherein the attachment mechanism that comprises the controllable
5 dynamic force damper comprises a strut.

47. The marine vessel of claim 44 wherein one of the attachment mechanisms other than the attachment mechanism that comprises the controllable dynamic force damper comprises a pivot mechanism constructed for direct
10 attachment of the hydroski to the buoyant vessel body through the pivot mechanism.

48. The marine vessel of claim 44 wherein the high speed is greater than 100 knots.

49. The marine vessel of claim 48 wherein the
15 high speed is greater than 150 knots.

50. The marine vessel of claim 44 wherein the planing element is buoyant.

51. The marine vessel of claim 44 wherein the planing element is non-buoyant.

20 52. A marine vessel comprising:
a buoyant vessel body;
a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
a plurality of planing elements attached to the
25 buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed travel of the marine vessel, by virtue of lifting action;
and

- 32 -

a plurality of attachment mechanisms attached to the planing elements and the buoyant vessel body, the attachment mechanisms having strength and rigidity sufficient to transmit lifting forces from the planing
5 elements to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

the planing elements having a configuration that permits the marine vessel to ground itself solely on the planing elements.

10 53. The marine vessel of claim 52 wherein the attachment mechanisms are controllably adjustable to shift the planing elements between a high-speed position in which the planing elements are displaced in a downward direction relative to the buoyant vessel body during the
15 high-speed travel of the marine vessel, and a low-draft position in which the planing elements are retracted upwardly so as to reduce draft for entry of the marine vessel into shallow water.

20 54. The marine vessel of claim 53 wherein the configuration of the planing elements that permits the marine vessel to ground itself solely on the planing elements is the low-draft position.

25 55. The marine vessel of claim 53 wherein the low-draft position of the planing elements reduces hydrodynamic drag during low-speed operation of the marine vessel in which the buoyant vessel body is in contact with water.

30 56. The marine vessel of claim 52 wherein at least one of the attachment mechanisms comprises a dynamic force damper.

- 33 -

57. The marine vessel of claim 56 further comprising:

- a sensor system attached to the buoyant vessel body to provide signal information pertaining to
5 interaction between the marine vessel and water waves during grounding of the marine vessel;
- a control system connected to the sensor system and to the dynamic force damper and configured to adjust the dynamic force damper in response to the signal
10 information from the sensor system to compensate for the interaction between the marine vessel and the water waves during the grounding of the marine vessel.

58. A marine vessel comprising:

- a buoyant vessel body;
- 15 a propulsive device attached to the buoyant vessel body to propel the buoyant vessel body at high speed;
- at least one planing element attached to the buoyant vessel body so as to lift the buoyant vessel body upward and out of contact with water during high-speed
20 travel of the marine vessel, by virtue of lifting action; and

- a plurality of attachment mechanisms attached to the planing element and the buoyant vessel body, the attachment mechanisms having strength and rigidity
25 sufficient to transmit lifting forces from the planing element to the buoyant vessel body to lift the buoyant vessel body upward and out of contact with water;

- the attachment mechanisms being controllably adjustable to shift the planing element between a high-
30 speed position in which the planing element is displaced in a downward direction relative to the buoyant vessel body during the high-speed travel of the marine vessel, and a docking position in which the planing element is displaced sideways relative to the buoyant vessel body so

- 34 -

as to serve as a fender during docking maneuvers of the marine vessel.

59. The marine vessel of claim 58 wherein the at least one planing element comprises a plurality of
5 planing elements.

1/19

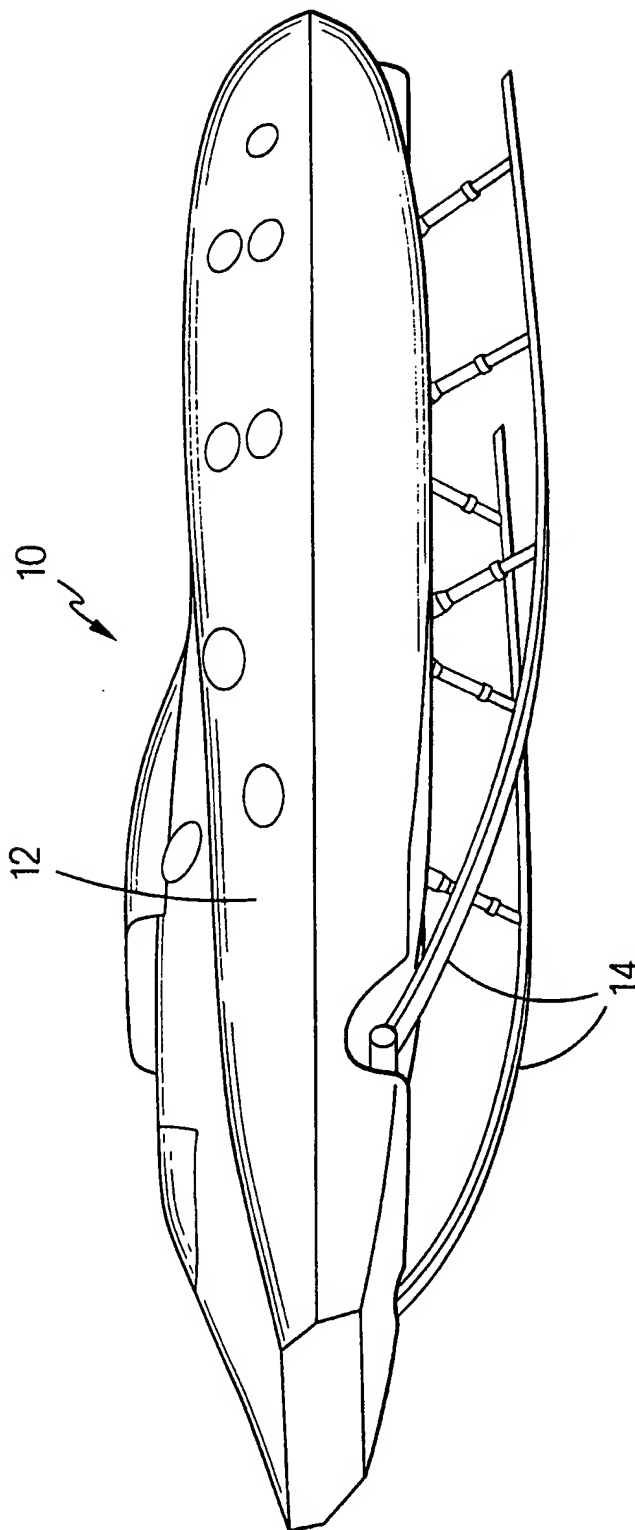


FIG. 1

2/19

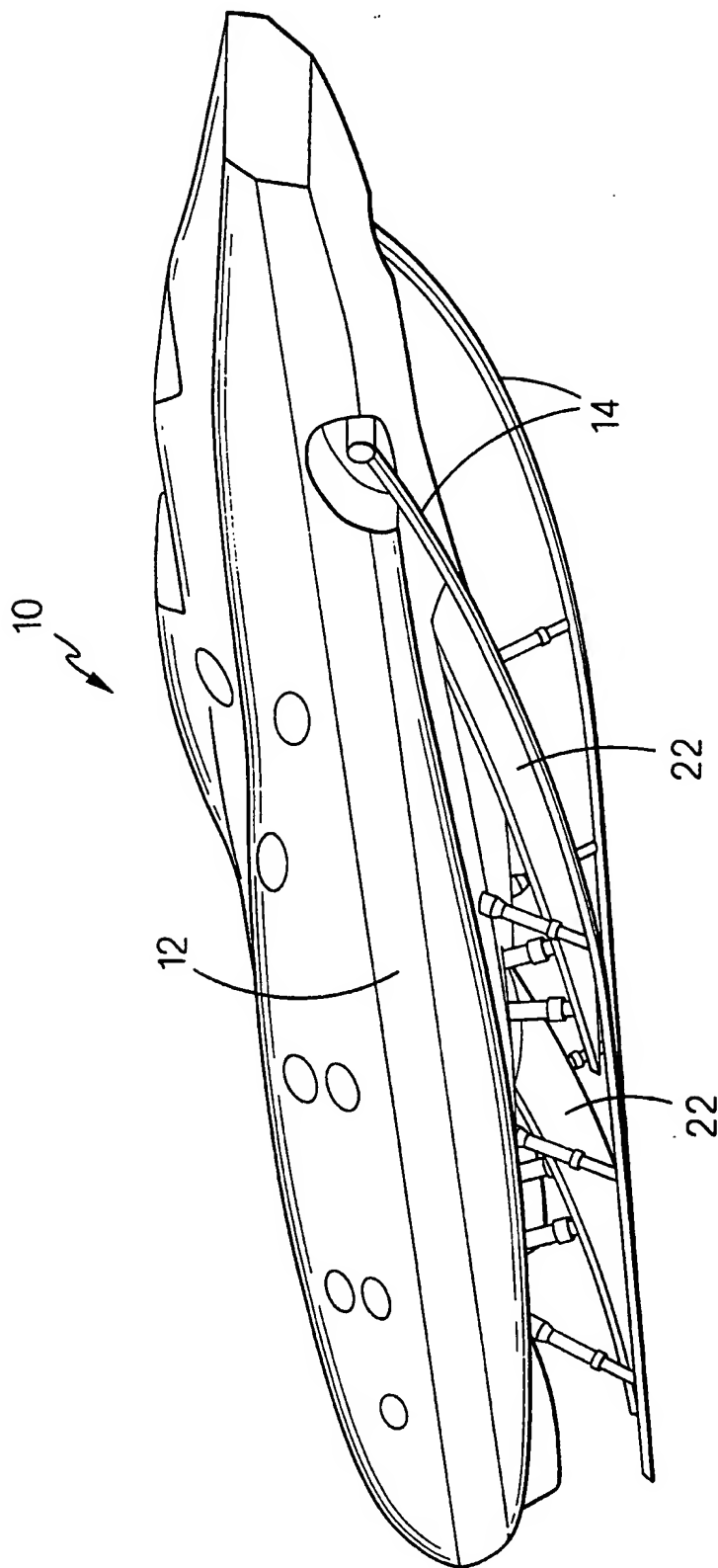


FIG. 2

3/19

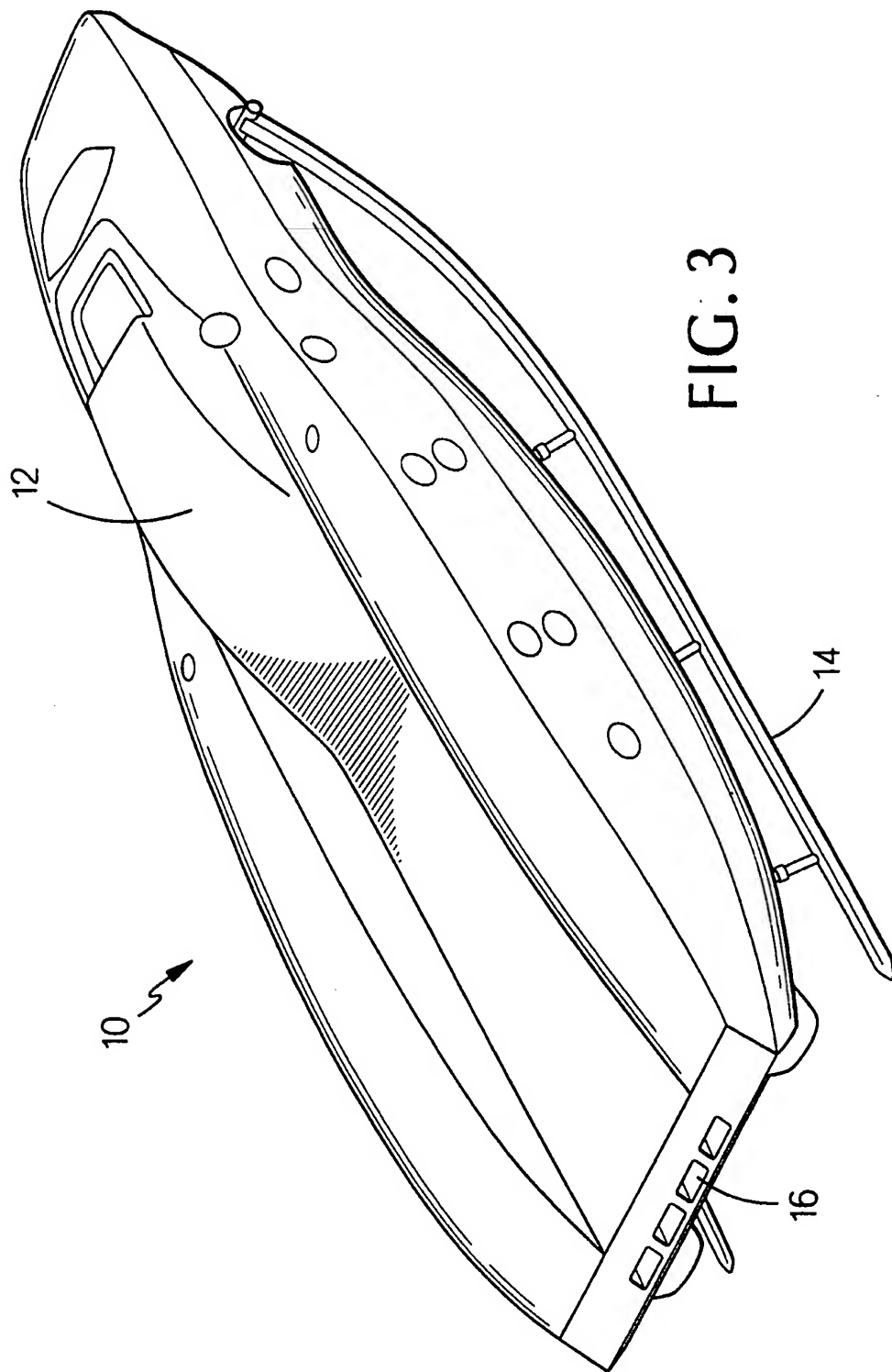
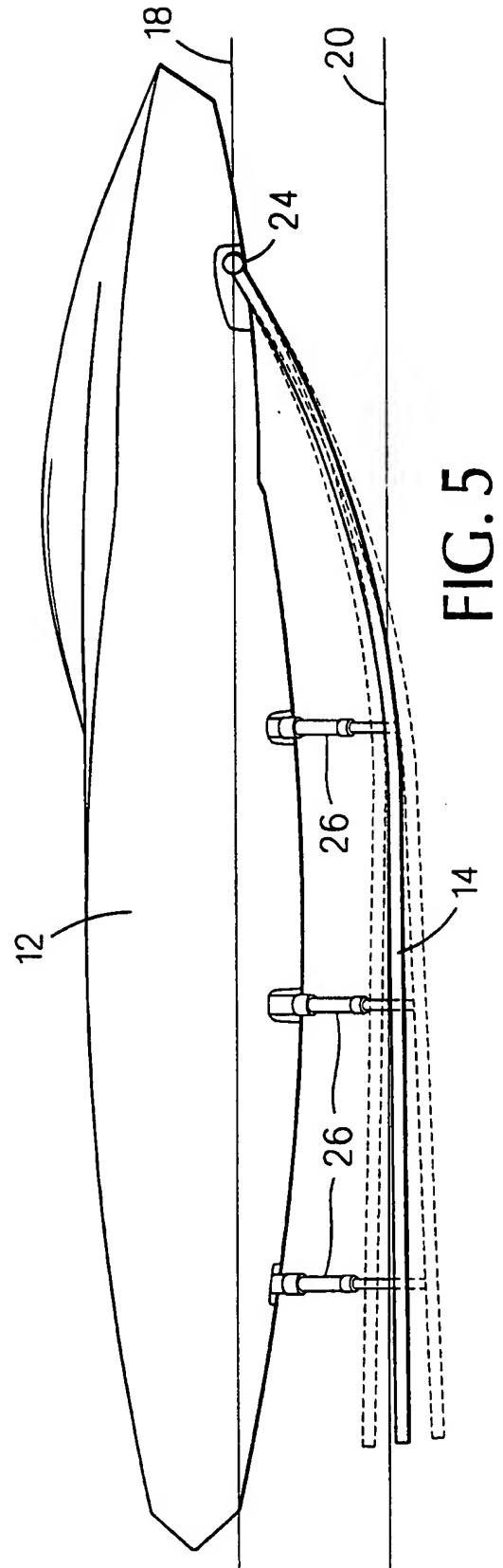
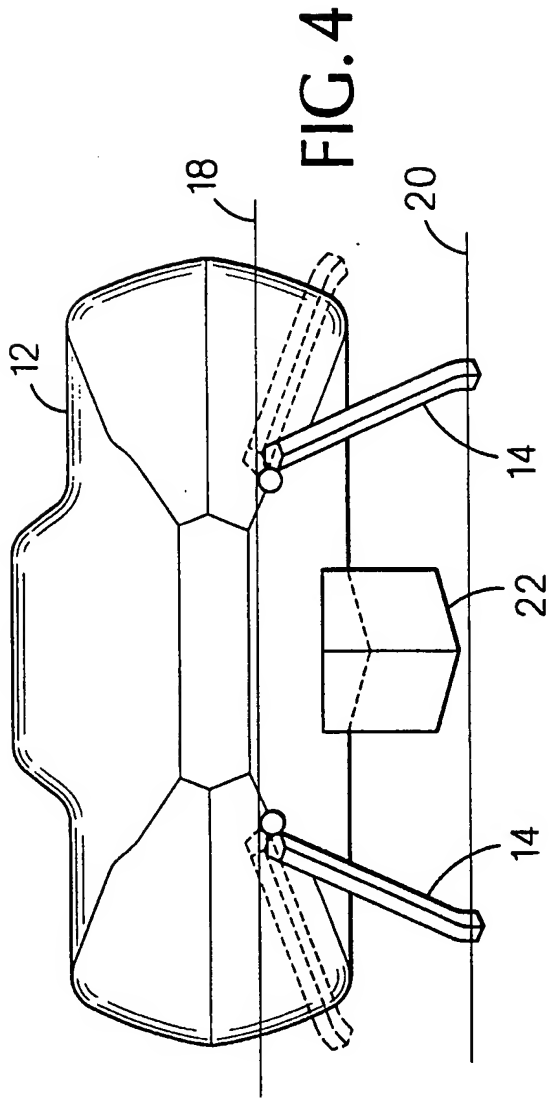


FIG. 3

4/19



5/19

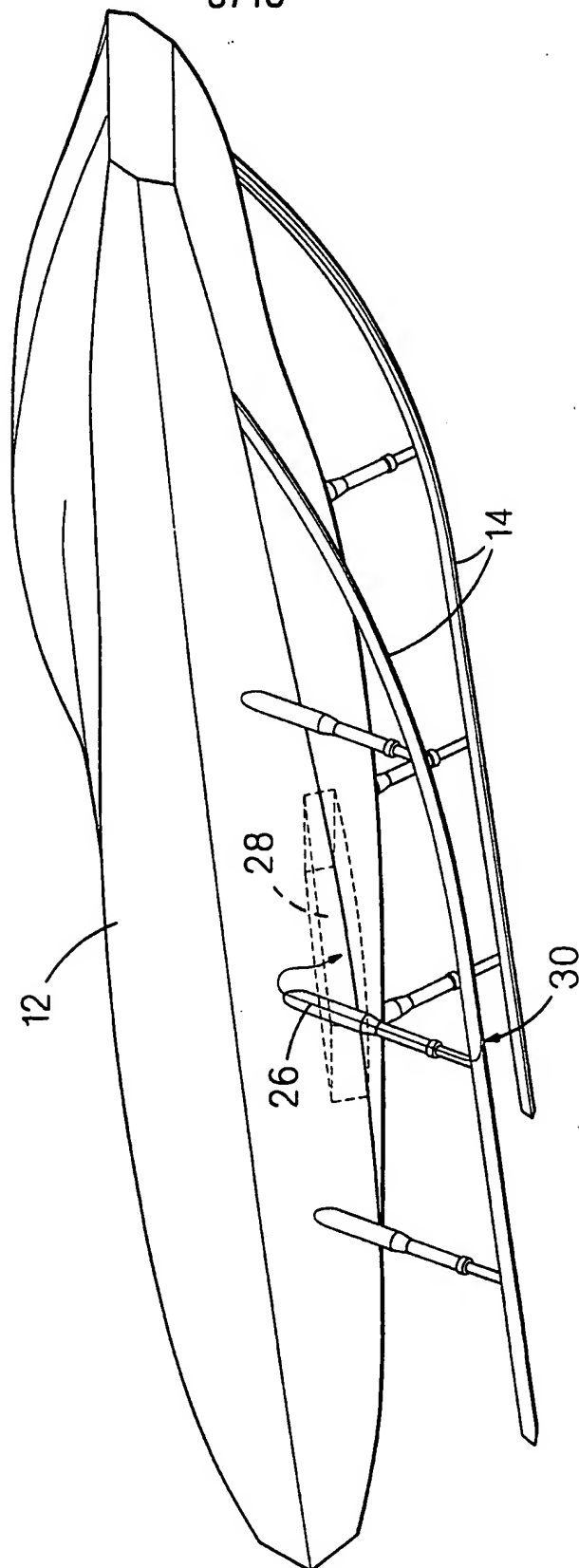
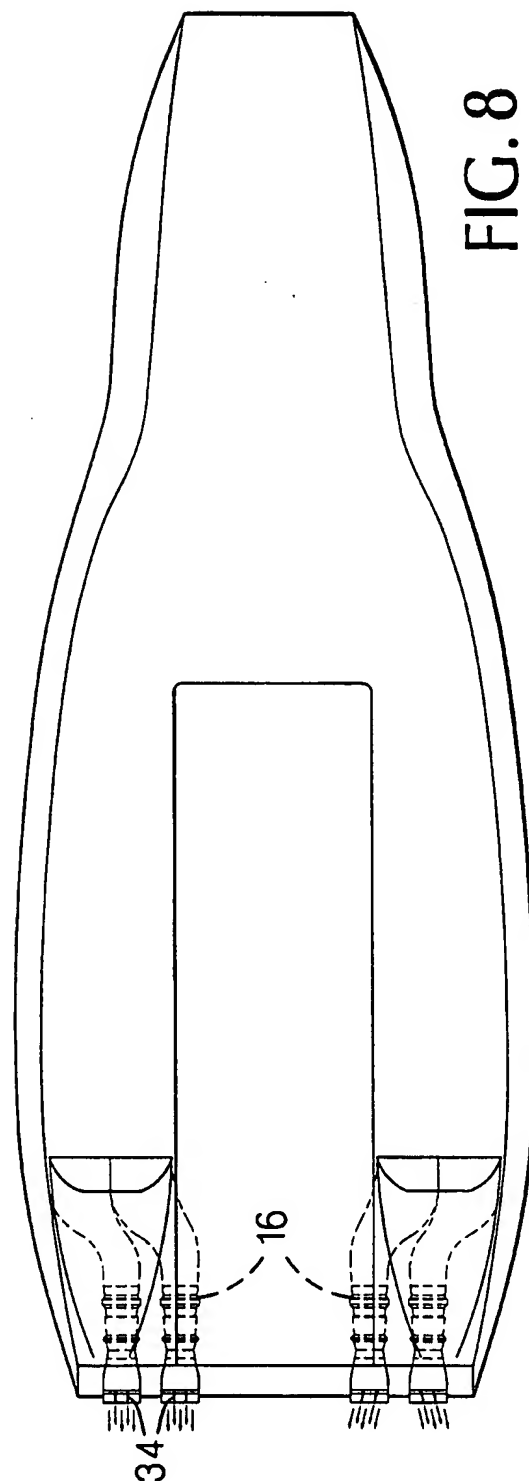
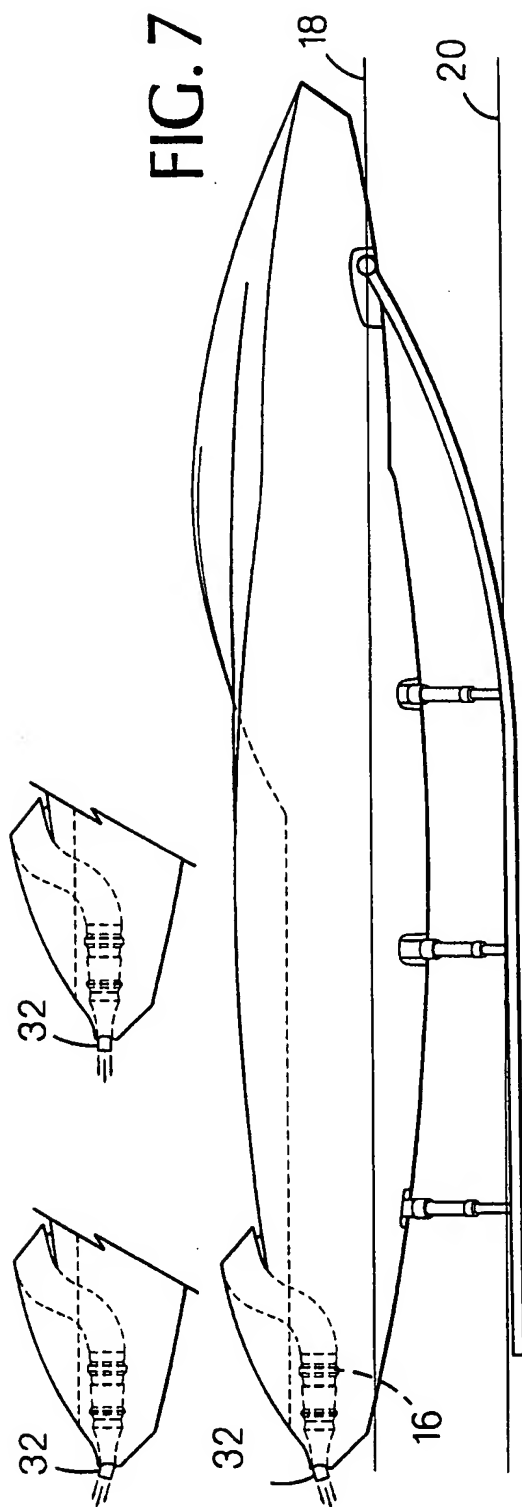


FIG. 6

6/19



7/19

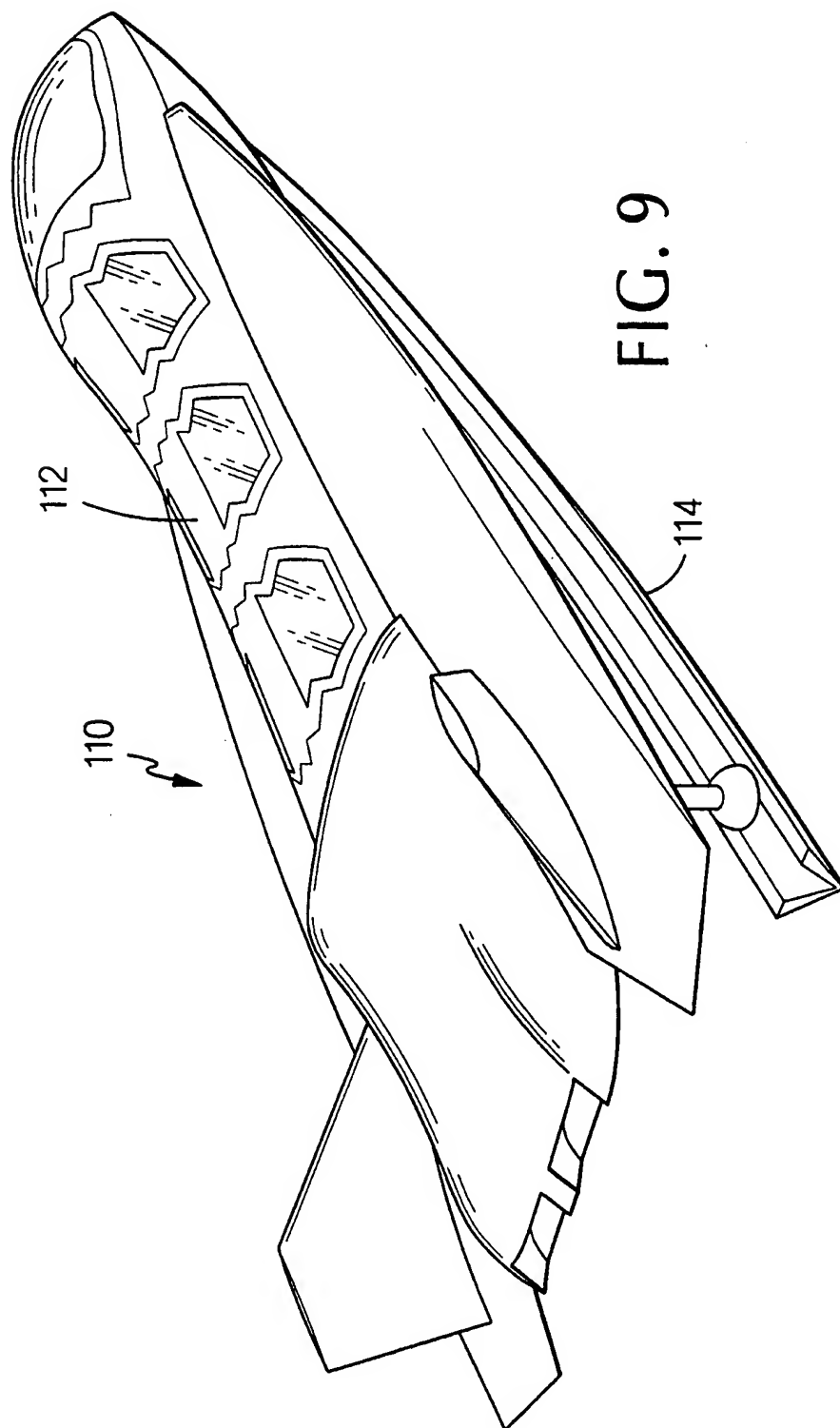


FIG. 9

8/19

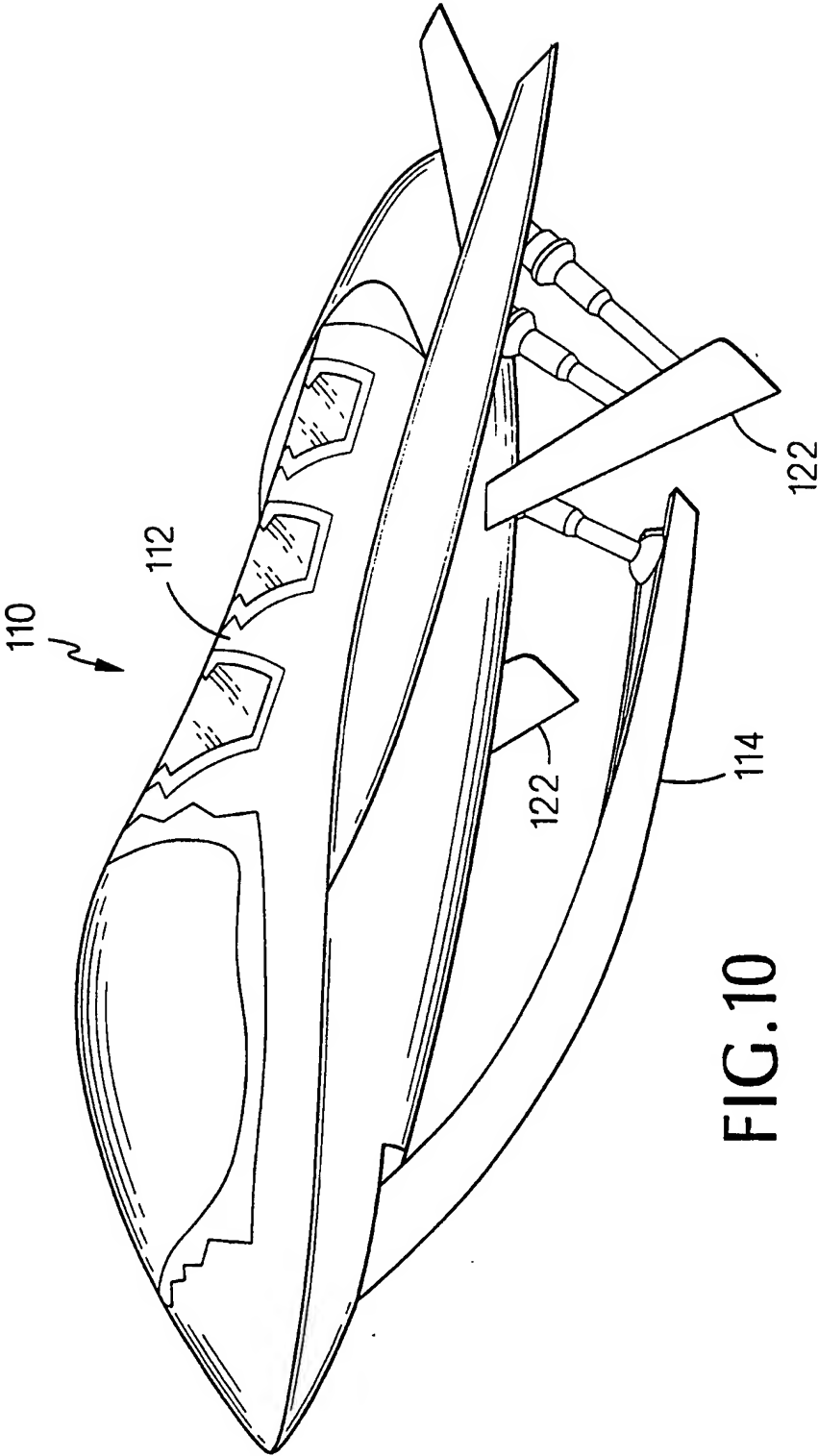


FIG. 10

9/19

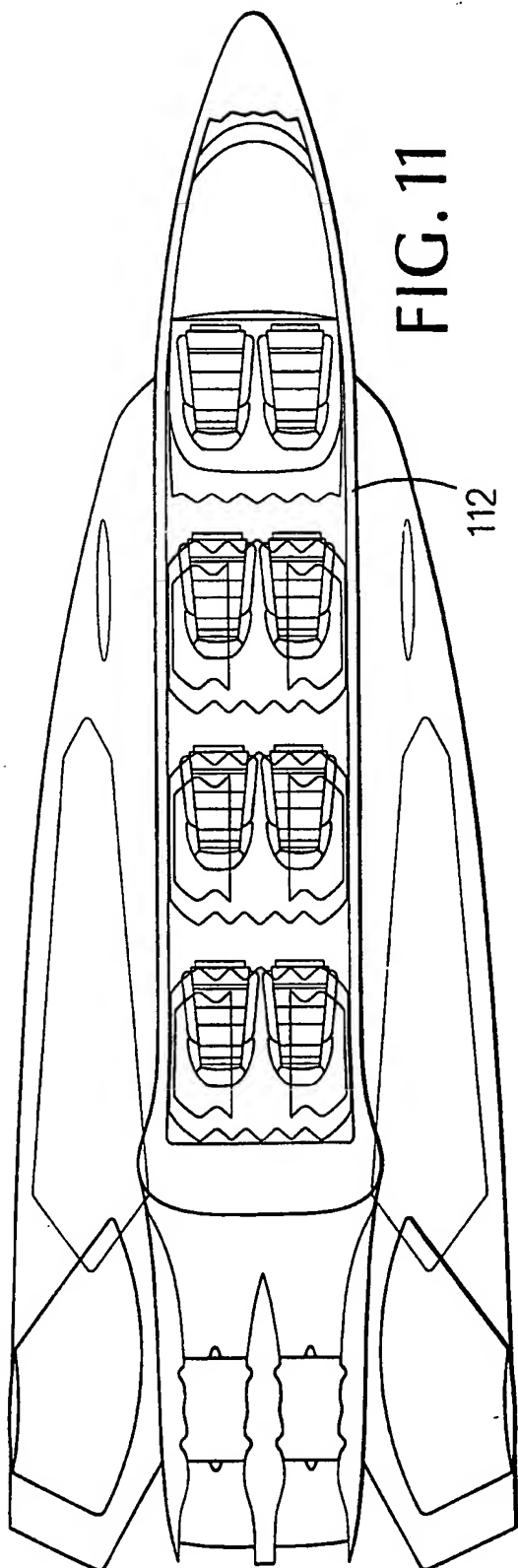


FIG. 11

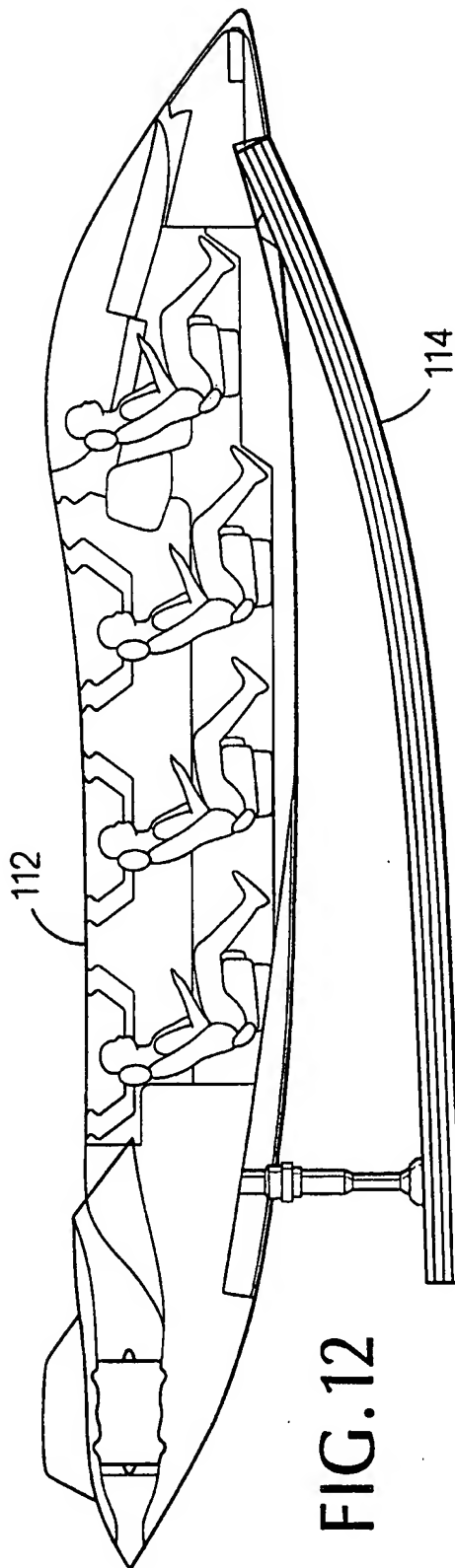


FIG. 12

10/19

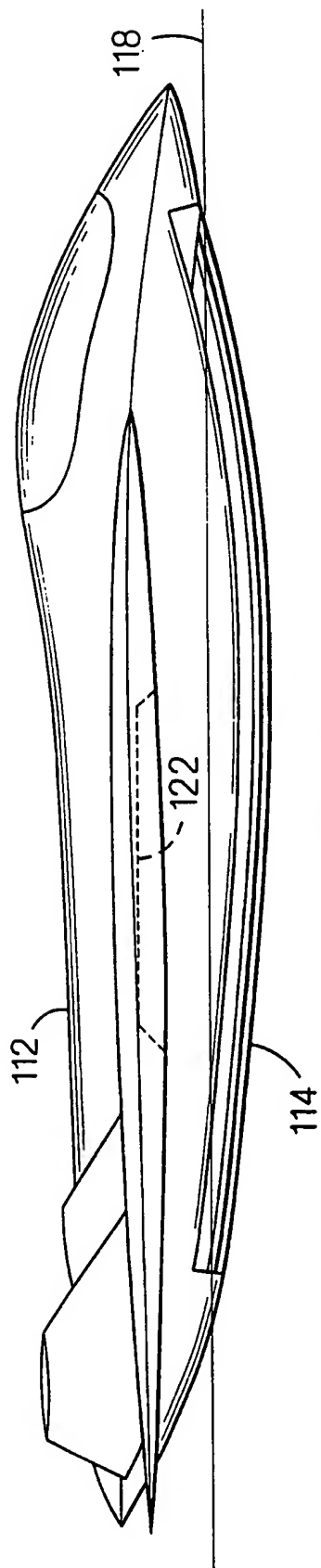


FIG. 13

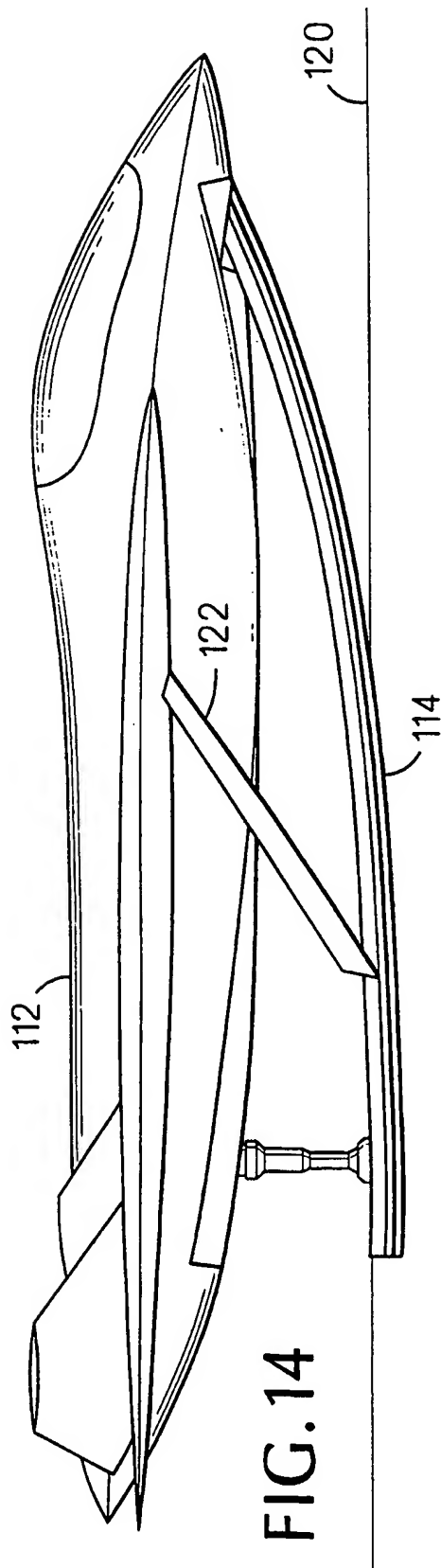


FIG. 14

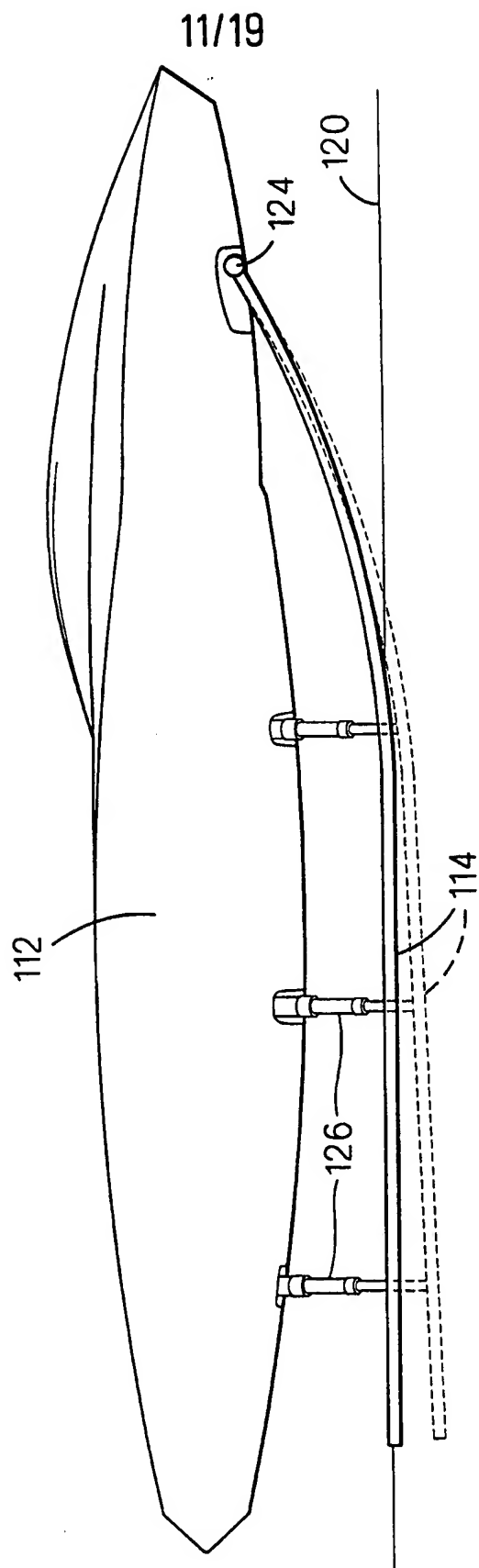


FIG. 15

12/19

FIG.17

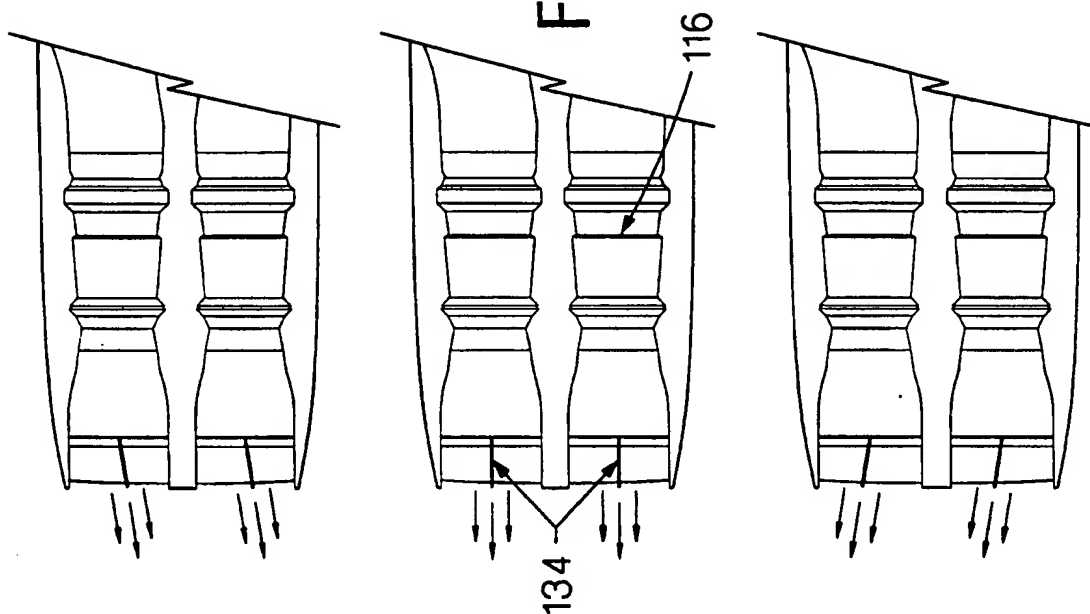
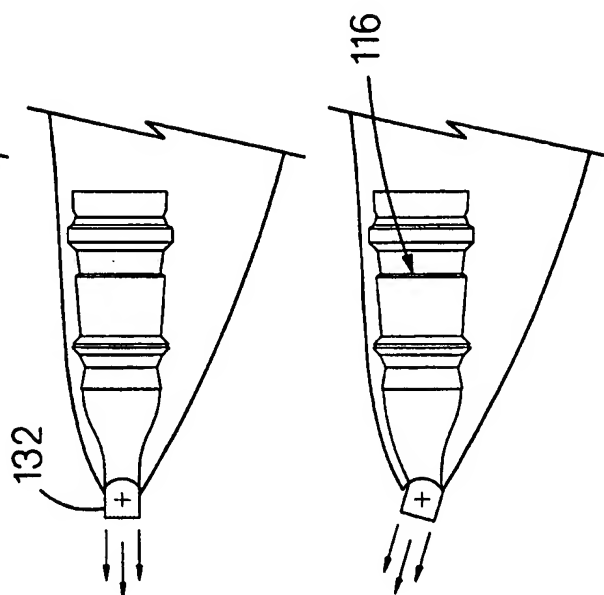


FIG.16



13/19

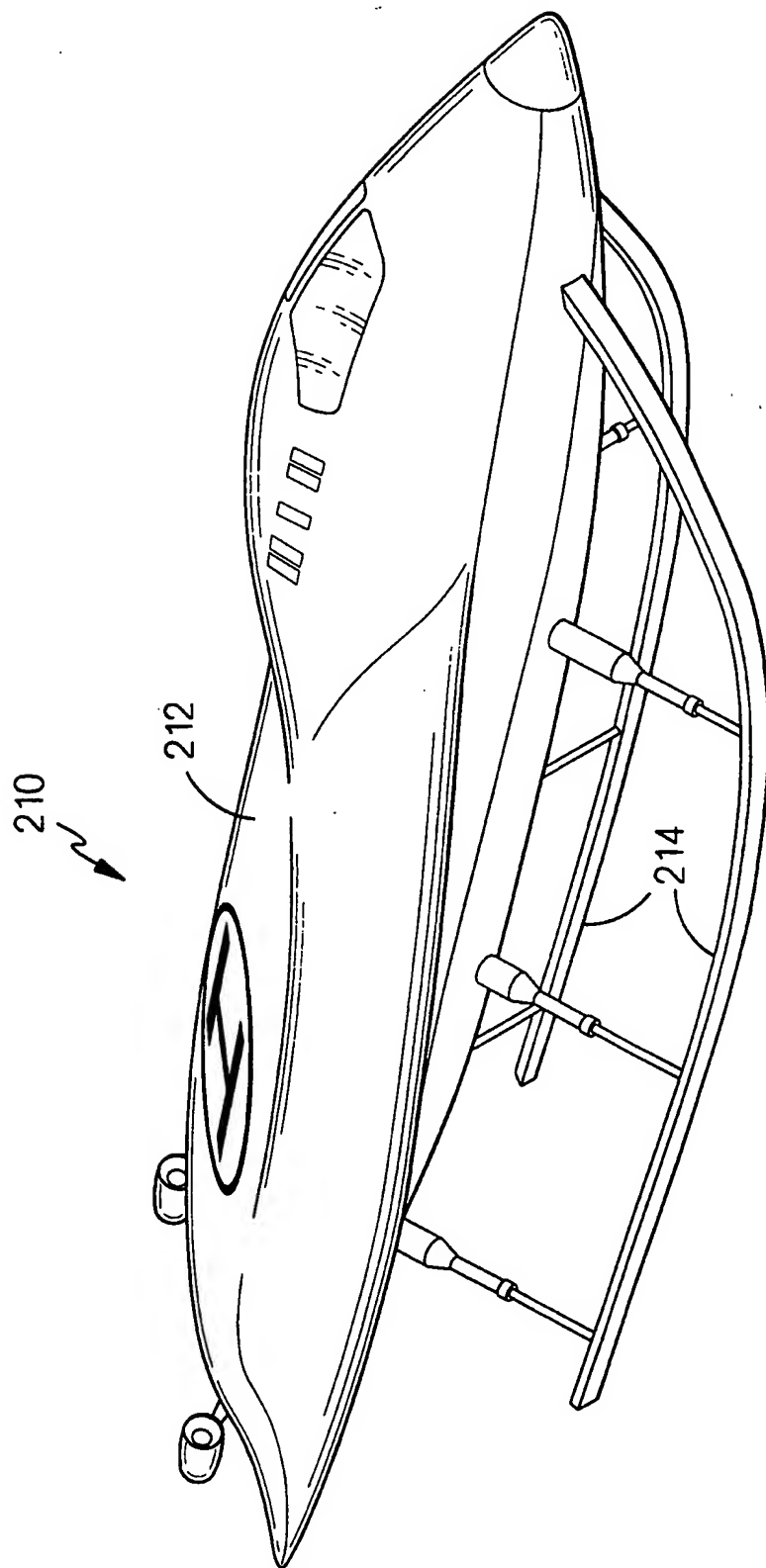
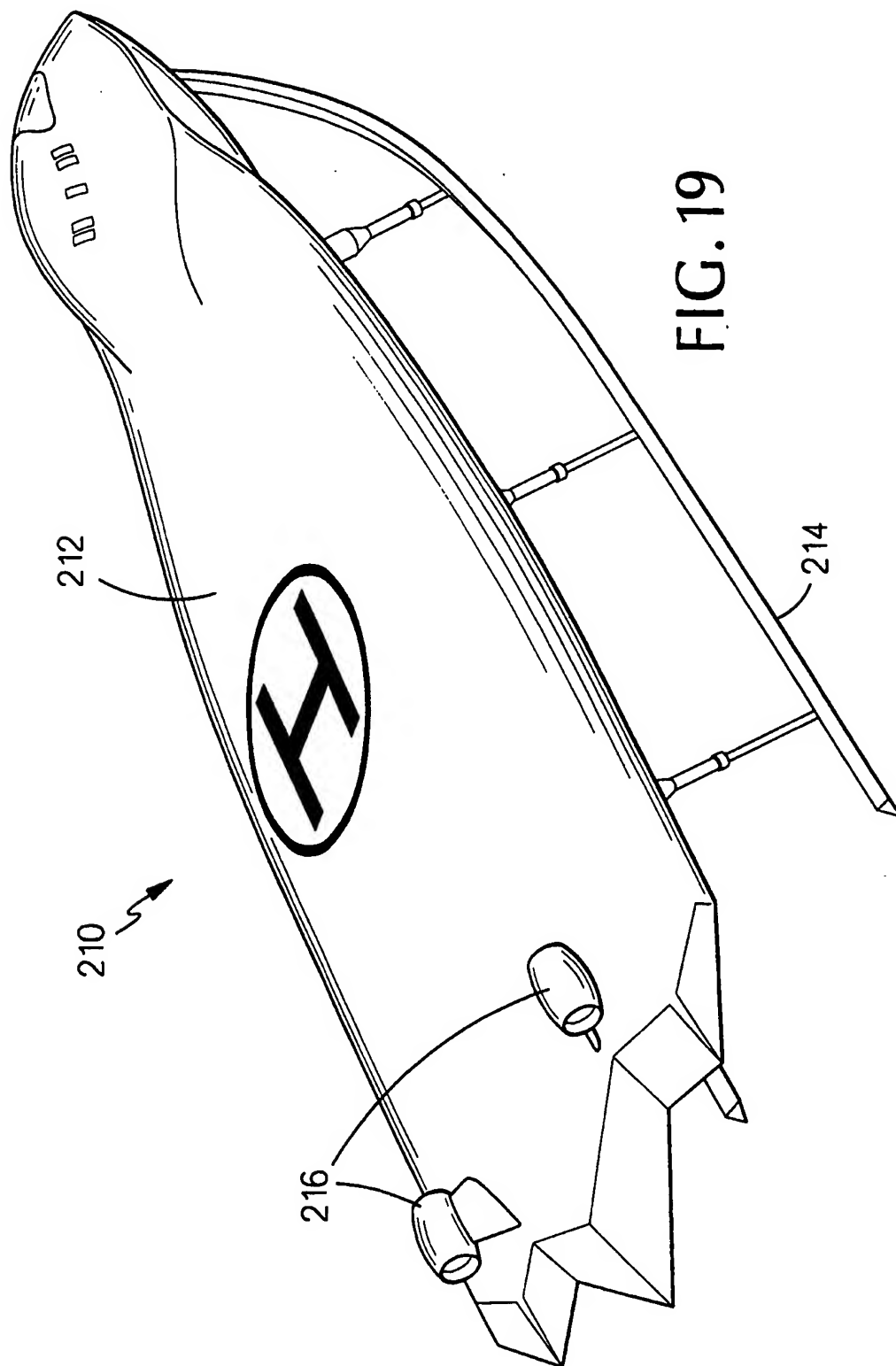


FIG. 18

14/19



15/19

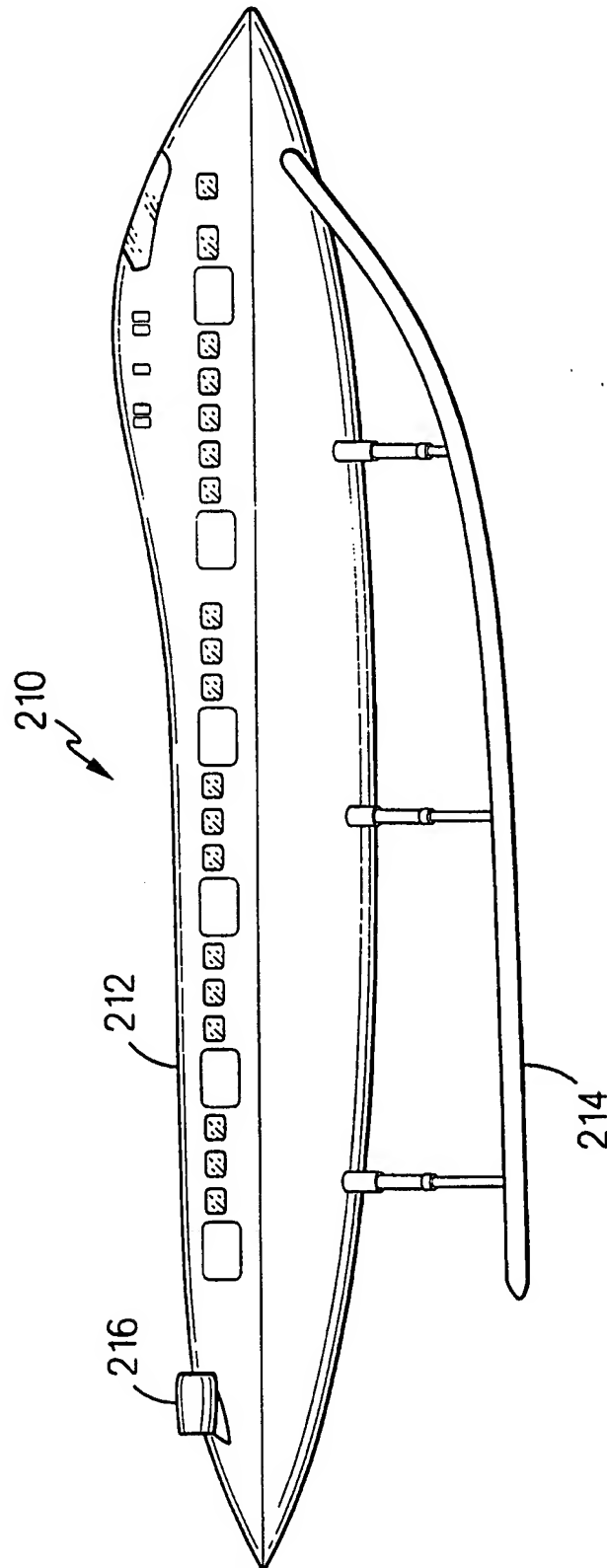
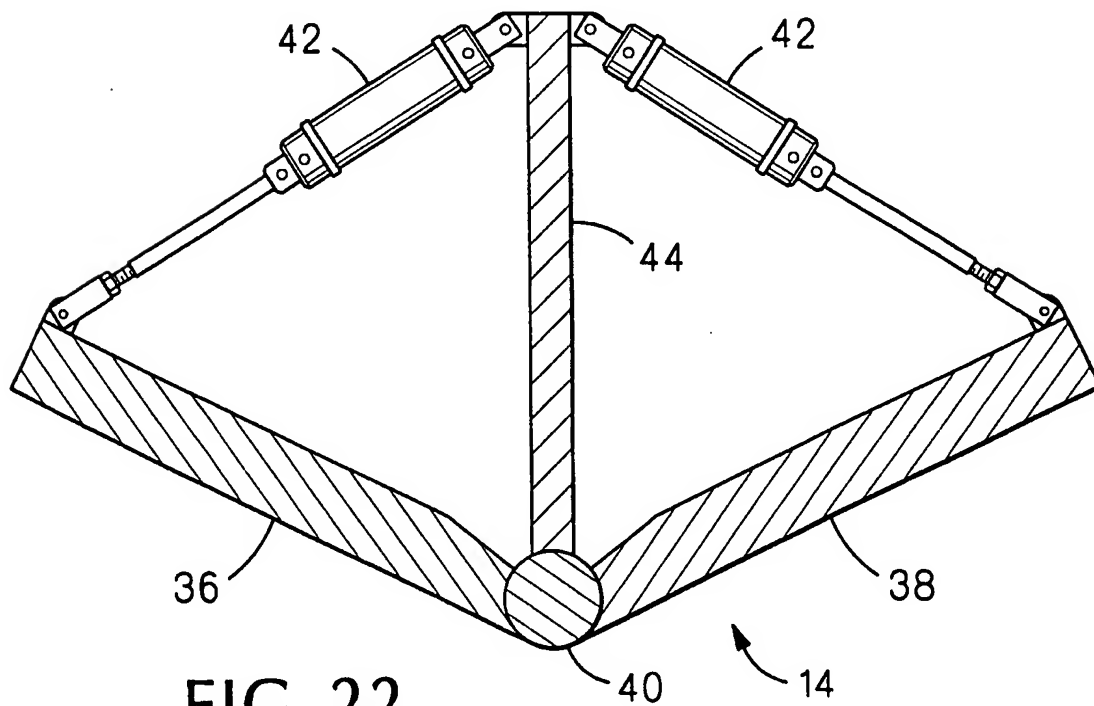
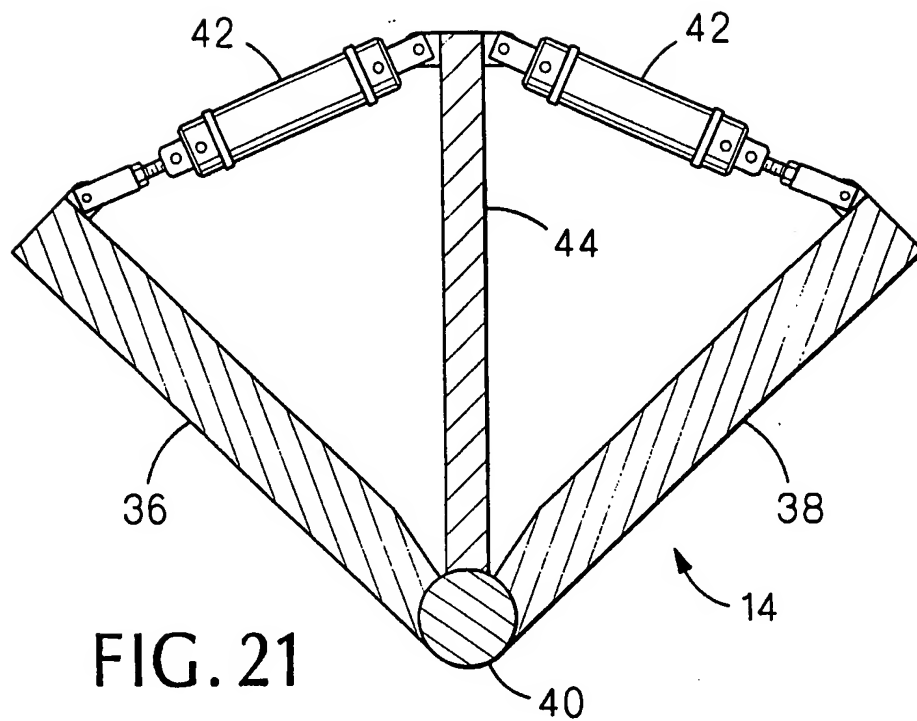


FIG. 20

16/19



17/19

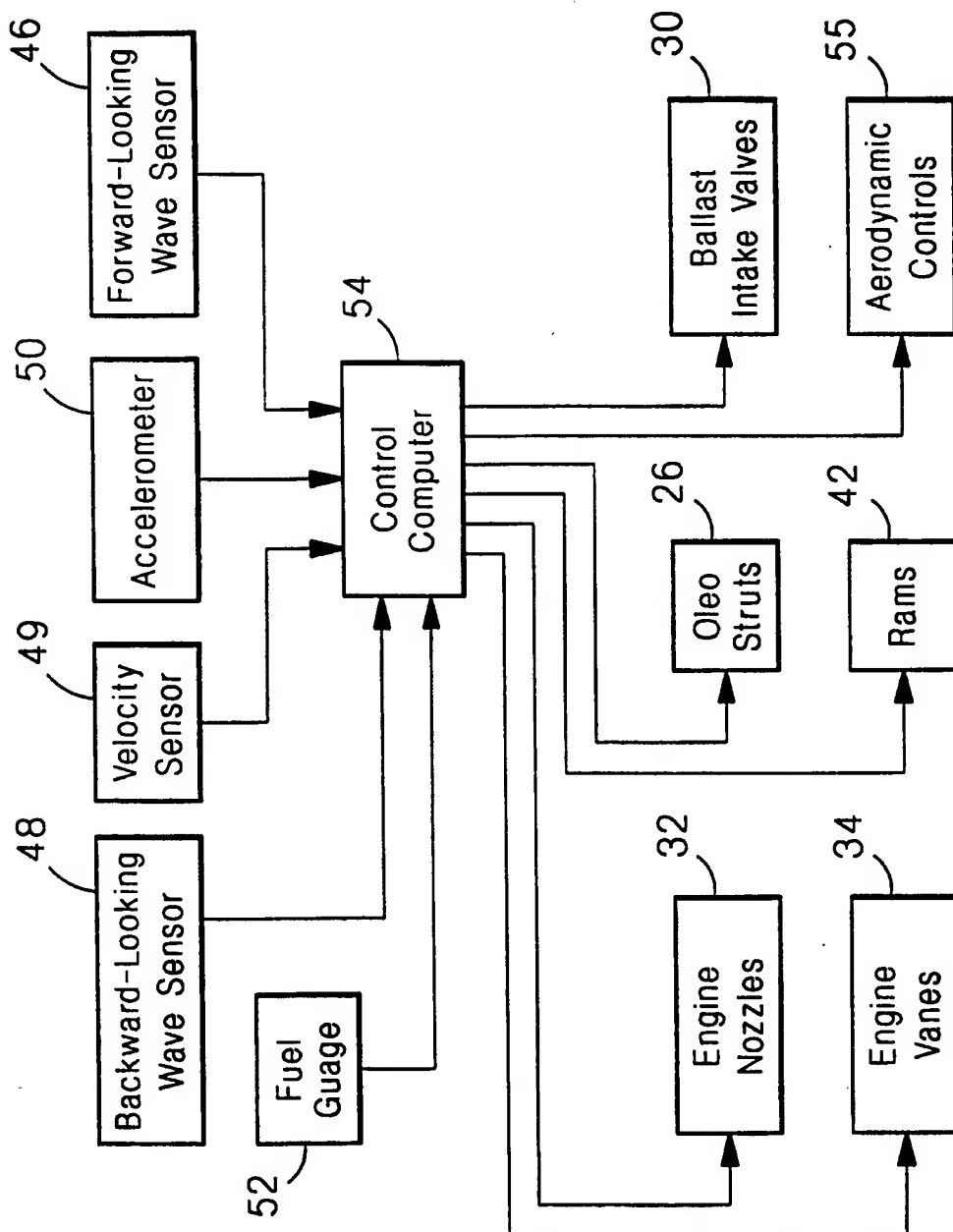


FIG. 23

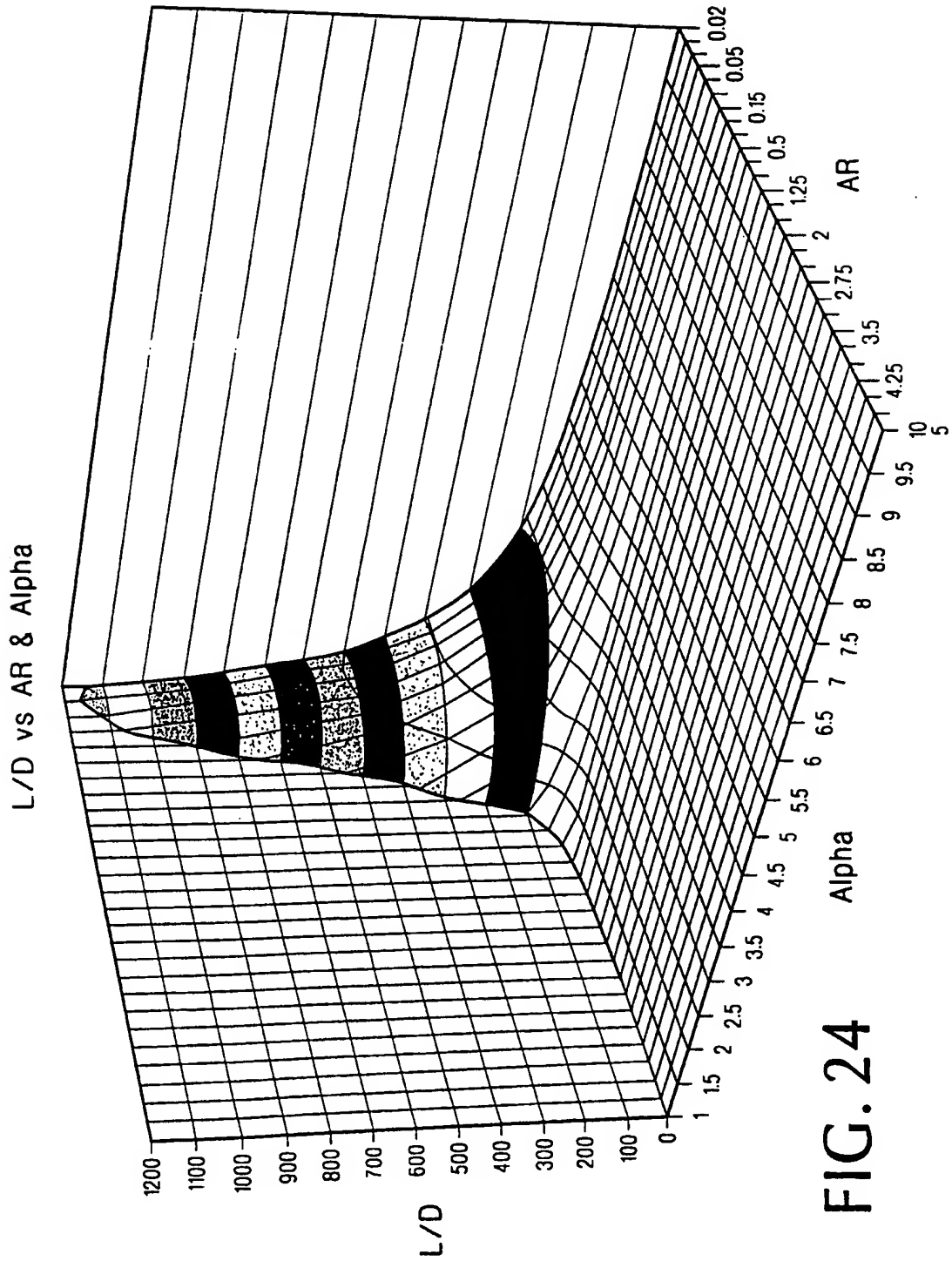
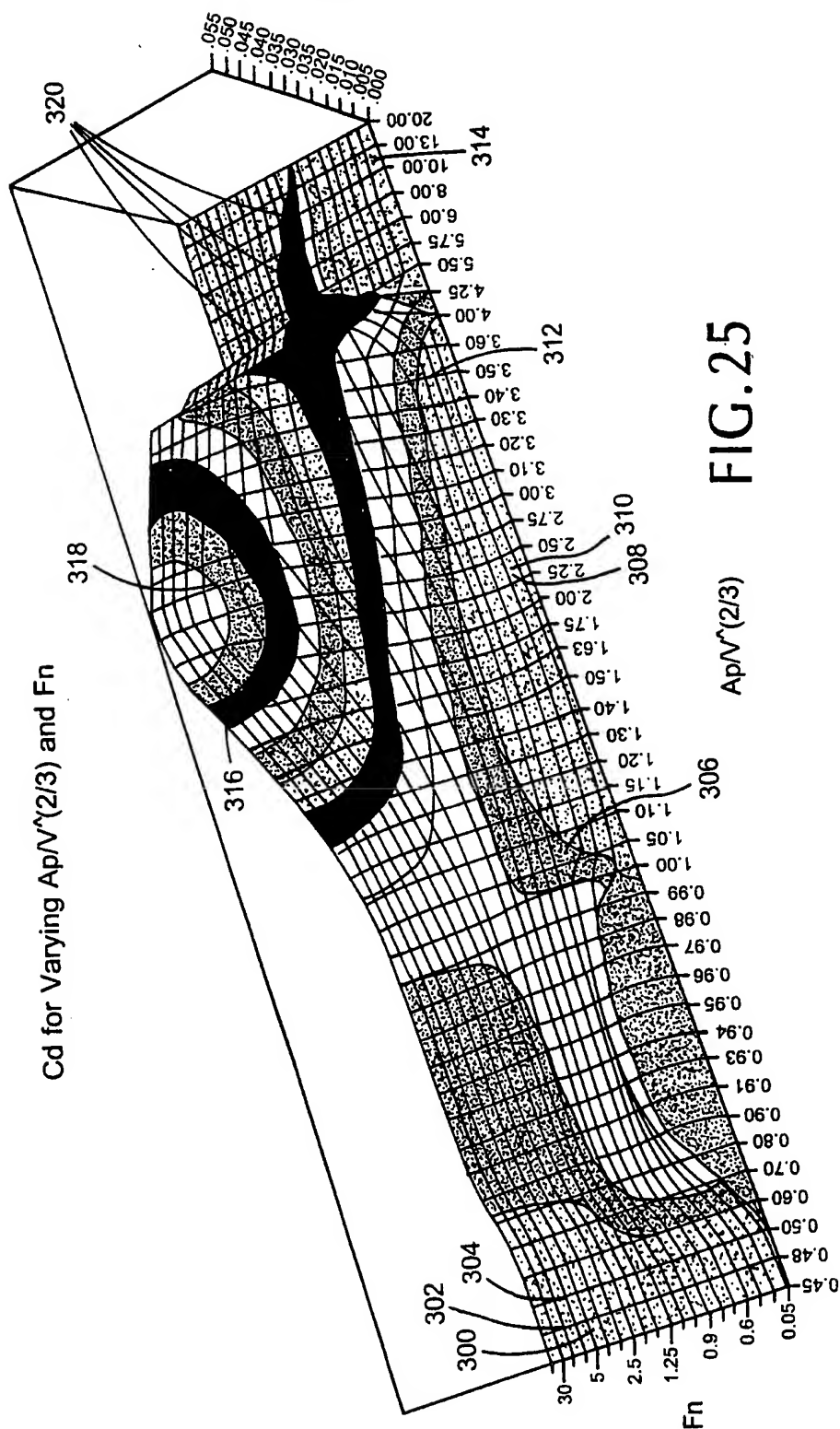


FIG. 24

19/19



INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US97/14987

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B63B 1/20

US CL :114/283

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 114/283,61,121,125,144e,270-278 440/38-42 D12/300,310

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
noneElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	JP 62-244,778 A (YUKIO KAJINO) 26 OCTOBER 1987 SEE ENTIRE PATENT	11,15, 21-24 ----- 1-3,5-8,12, 13,16- 20, 25, 26
X ----- Y	US 5,619,944 A (BAKER) 15 APRIL 1997, SEE ENTIRE PATENT	11,14,20 ----- 1-8
X	US 5,265,550 A (HARPER, JR.) 30 NOVEMBER 1993, SEE ENTIRE PATENT	52-55,58, 59
X	US 4,685,641 A (KIRSCH ET AL.) 11 AUGUST 1987, SEE ENTIRE PATENT	52-56

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

14 NOVEMBER 1997

Date of mailing of the international search report

12 DEC 1997

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

ED SWINEHART

Telephone No. (703) 308-1113

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/14980

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 2,647,709 A (DOOLITTLE ET AL.) 04 AUGUST 1953, SEE ENTIRE PATENT	27,28 ---- 29-31
Y	US 3,987,743 A (PENSEL) 26 OCTOBER 1976, SEE ENTIRE PATENT	9,10,19,20,25,26 29,30
Y	US 3,157,146 A (BILLIG) 17 NOVEMBER 1964, SEE ENTIRE PATENT	31

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/14987**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 27-31,33-51 and 57
because they relate to subject matter not required to be searched by this Authority, namely:

The specification is objected to as failing to provide an adequate written description of the control arrangement of the thrust vectoring system and planing element supports responsive to sensed wave conditions.
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☒ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.